# Determinants of Consumption-Based Carbon Emissions: Evidence from Brazil

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**Abstract**

This paper aims to investigate the drivers of consumption-based carbon emissions in Brazil by using a dataset between 1990 and 2018. These dynamics were examined by employing ARDL bounds, FMOLS, DOLS and gradual shift causality tests. Findings based on ARDL long and short-run estimations reveal that; (a) renewable energy usage improves the environmental quality; (b) economic growth increase environmental degradation; (c) technological innovation improves the quality of the environment; (d) public-private investment in energy improves environmental sustainability; and (e) electricity consumption harms the quality of the environment. Moreover, the results of the gradual shift causality support the results of ARDL, FMOLS and DOLS. Therefore, policymakers in Brazil should actively promote the research and development of low-carbon technologies and renewable energy consumption while domestic consumption level should be targeted, especially those sectors which are more energy-intensive and causing to increase consumption-based $CO_2$ emissions.

**Keywords:** Consumption-Based Carbon Emissions; Technological Innovation; Environmental Quality; Public-private investment in energy

## 1. Introduction

The use of energy, otherwise termed as energy consumption, involve numerous activities such as economic, industrial, tourism, globalization, and urbanization etc. However, there is a global concern that energy consumption emanate carbon or greenhoushe gas into the atmosphere which degrade the quality of environment and cause global warming. According to the Enviromental Protecting Agency (EPA, 2018), transportation sector is the emanates large percentage (28%) of carbon emission to the environment. This was followed by electricity (27%), industry (22%), commercial & residential (12%), and agriculture (10%).

According to World Bank Dataset (2020), carbon emissions in Brazil has increased progressively within the years. In 2000, it increased from 327983.8 kilotonnes (kt) to 337433.7kt. In 2005, it increased to 347668.3kt, 347668.3 in 2006, 363212.7kt in 2007, 387631.2kt in 2008. However, in 2009, it dropped to 367147.4kt before it rose gain to 419754.2kt in 2010. Since then, there had been continuous increase and it had hit 533530.2kt as at 2014. Meanwhile, the government of Brazil could reduce its total amount of greenhouse gases by more than 37% by 2030 while maintaining the set development goals without negatively affecting economic activities. It is widely accepted that as energy consumption increases, the greenhouse gas emission (carbon emission) tend to increase, and for proper development of economic activities of a country such as Brazil, large amount of energy use – renewable or nonrenewable – is required. For instance, in 2000 energy consumption was 1072.38kg when carbon emissions were 327983.8kt, in 2007, it had increased to 1238.412kg and carbon emissions subsequently increased to 363212.7kt and in 2014 energy consumption was 1495.541kg and carbon emissions to increase to about 533530.2kt. The international energy association says Brazil energy policies measure up well against the world's most pressing energy challenges. The renewable energy in Brazil covers close to 45% of energy demand, thus making Brazil one of the least carbon's intensive in the world. Generally, electricity production and consumption in Brazil has continued to rise with 80% of domestic electricity generation from large hydropower plants. As of 2014, Brazil's carbon emissions had risen to about 2.61 metric tons showing that it increased from 0.65 metric tons from 1960.

The drivers of consumption-based carbon emissions spread across different economic sectors and the percentages of emissions contributed differs. The level of tourist's arrivals affects the level of energy consumption which also affects the amount of carbon dioxide and other greenhouse gases emitted. This may be due to the fact that the amount of energy consumption increase, experienced by such countries determines their international population and in the long run, determines other economic activities such as transportation. More so, the development of industries for the production and transformation of goods in form of industrialization may lead to increased energy consumption thus increased consumption-based carbon emissions. A long-term causal link may exist between the consumption of energy, industrial activities and carbon emissions with energy consumption granger causing carbon pollutions, industrial development, and financial development in the long run. Environmentally, conscious industrial policies are imperative towards attaining the goal of environmental quality and control global warming (Shahbaz et al., 2014).

Based on the above exract, consumption-based carbon emissions cannot be separated from other forms of energy due to the need for energy use for economic and industrial activities. Thus, this present study used Brazil as a case study to contribute to the literature in the following ways: (a) we employed the consumption-based carbon emissions ($CCO_2$) as the proxy of environmental degradation. $CCO_2$ is essential because it not only takes the global supply chain into account but also contributes to the creation of emissions and distinguishes between pollutants created in one country and used in another. (b) we employed gradual shift causality test to capture the long-run causal linkage between the series. Unlike several conventional causality tests, the Gradual shift takes into account the effect of a structural break (s). (c) the study utilised ARDL approach to capture long and short-run interconnection among the series, and (d) the Zivot-Andrews unit root was utilised to catch the stationarity features as well as single break in series. This study takes a step further by adopting indicators, such as renewable energy, economic growth, electricity consumption, and technological innovation as well as a public-private partnership in energy. This is because energy consumption is certain numerous activities, hence identifying the drivers of $CCO_2$ resulting from energy consumption and providing policy recommendations towards mitigating environmental degradation becomes the major priority of this study.

In what follows, we discuss the literature in line with the current trend of each variable in the literature. Next, section three presents details of data used alongside the methodological foundation of this study. The results are presented and discussed in section four, while section five concludes the study with vital policy implication and energy policy suggestions for Brazil and other countries.

## 2. Literature Review

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### 2.1. Empirical Review

#### 2.1.1 Energy Consumption, Economic growth, and Carbon emission

Several studies have considered the impact of energy consumption and carbon dioxide emissions (Hanif et al., 2019; Yildirim et al., 2012; Adams & Nsiah, 2019; Long et al., 2015). Energy consumption is a major contributor to carbon dioxide emissions. This emission from energy consumption results from either commercial or residential activities. The amount of carbon emitted may depend largely on the type of energy consumed either renewable or non-renewable energy. Hanif et al. (2019) adopted the generalised method of moments (GMM) to investigate global carbon emanations, and non-environmentally friendly power utilization in developing economies in Asia continents. They discovered that utilizing energies from renewable sources help control the amount of carbon dioxide emitted while the reverse is the case for non-environmentally friendly power utilization in these developing economies of the world. Also, aside from ensuring the transition from non-renewable to renewable energy consumption, Regular asset consumption and populace and population pressures contribute greatly to carbon emissions. Similarly, Adams and Nsiah (2019) seek to identify whether or not reducing renewable energy mattered in the emissions reduction goal of countries. It was discovered that energies from renewable and non-renewable sources contribute to an increase in carbon emissions although the number of emissions resulting from consumption of non-renewable energy is more than emissions from renewable energy.

Another variable that contributed immensely to environmental degradation is economic growth. Long et al. (2015) investigated the relationship that may exist between non-sustainable power, sustainable power, carbon dioxide emanations and financial development in a fast developing country such as China. It was evident that coal has a dominating impact on the growth of china's economy and the increase in the carbon dioxide emissions of the country. Also, a gross domestic product has a two-way causal relationship with carbon dioxide emissions, coal, and gas as well as electricity consumption. This has therefore made it quite imperative to make changes in the global consumption of energy to ensure drastic reduction in the quantity of carbon emissions resulting from energy consumption. This is why energy source like coal needs to be reduced and important to develop hydro and nuclear power in China. Importantly, Zhang and Cheng (2009) investigated the relationship between the consumption of energy, emissions of carbon dioxide and economic growth. They discovered that a unidirectional relationship runs from gross domestic product to energy consumption and the same relationship exists between energy consumption and carbon dioxide emissions. It is evident from the findings that neither carbon discharges nor energy utilization prompts financial development. The Chinese government should be equipped for guaranteeing moderate energy strategy and carbon discharges decrease strategies over the long haul hindering monetary development. Qing et al. (2021) assess the impact of energy productivity and eco-innovation on consumption-based carbon dioxide emissions IN G7 countries, the result of the study revealed that the primary drivers of $CCO_2$ emission are economic growth and renewable energy, thus, these two variables elevate the carbon emission in G7 countries. However, this result is in line with the study of Zeeshan et al. (2020c) where the long run relationship was established between renewable energy and $CCO_2$. In the study, the $CCO_2$ is negatively affected by renewable energy, thus help in lessen the environmental degradation to accomplish sustainable development in the country. Furthermore, Zeeshan et al. (2020b) find the same outcome in China, indicating that $CCO_2$ emission is dimished with the help of renewable energy.

Also, Investigating the driving forces behind the carbon emissions resulting from energy consumption in china Yang et al. (2019) found that economic activities are the major driving forces of carbon dioxide emissions with energy intensity being a huge suppressor of carbon emissions. Policies such as optimization of the structure of the industries improved energy structure and most importantly optimizing the consumption of clean energy can effectively suppress the growth of carbon emissions. However, the role of economic growth in energy consumption cannot be overemphasized. Yildirim et al. (2012) attempted to provide evidence of the relationship that exists between energy consumption and economic growth from renewable energy. It was discovered that bio-mass waste-derived energy consumption exerts a one-way causal relationship on real gross domestic products (GDP) while other renewable energies like geothermal, hydro-electric, biomass and bio-mass wood-derived energy consumption have no causal link with GDP. This implies that converting waste to an energy source not only prevent waste dumping can also contribute to GDP by serving as a source of renewable energy.

Meanwhile, testing the energy consumption and economic growth link, Odhiambo (2009) found that a stable long-run relationship exists between the total energy consumption per capita and electricity consumption per capita. Also, a unidirectional causal relationship runs from total energy utilization and monetary development i.e., the consumption of energy improves economic growth. Similarly, investigating energy utilization and monetary development, Tsani (2010) found a unidirectional causality from the total energy consumption to GDP. This implies that despite emission reductions goals, energy consumption is an important tool for ensuring economic growth. The economic expansion which usually results in increased energy consumption may lead to increased emissions of carbon dioxide on the other hand. Adedoyin and Zakari (2020) – while investigating the role of the uncertainty associated with economic policy on energy utilisation, economic growth and carbon –emissionsfound a unidirectional causality from energy consumption to economic growth. Also, economic policy uncertainties may exert a positive influence on climate change in the short term but in the long-run economic policy, uncertainty creates an unhealthy environment. The governments of countries with carbon reduction goals and economic growth at the same time should ensure efficient use of energy resources and provide adequate financial support to the environmentally friendly energy projects at low interests. Importantly, the relevance of a clean environment should be highlighted in the educational syllabus of institutions.

### 2.1.2 Internation trade, public-private partnership, and carbon emission

Over years, several studies (e.g. Demet & Kirikkaleli, 2019; Odugbesan & Adebayo 2020; Adedoyin et al. 2020; Kirikkaleli et al. 2020; Shahbaz et al. 2018; Khan et al. 2020; Umar et al. 2020) have been conducted, on the interaction trade, environmental degradation, investment and economic growth. Nonetheless, their results are mixed. For instance, Zhou et al. (2019) noted that examining the impacts of urbanization on increasing energy consumption-based emission requires urgent attention. Thus, in their assessment, they found that the role of urbanization on carbon emissions differ with the different subsystems of urbanization. Economic urbanization leads to an increase in carbon emissions i.e. a positive relationship implying that economic urbanization leads to an increase in carbon emissions activities. Population urbanization, on the other hand, exerts two opposing influence on carbon emissions i.e., population density has a negative impact on carbon emissions while a positive relationship exists between the proportion of urban and emissions of carbon dioxide. Also, construction of new infrastructures and conversion of existing land use in form of spatial urbanization leads to increased emissions considering the construction processes. Social urbanization was found to have a negative correlation with emissions majorly when there is improved low-carbon awareness by the general public. The difference in the effect of the various type of urbanization on carbon emissions indicates the need to consider the different aspects of urbanization while formulating emissions reduction measures. Zeeshan et al. (2020c) treated import and export separately for international trade and investigate its long run and short run impact on $CCO_2$ for oil-exporting countries. The study revealed that in both long run and short run, there is adverse effect of exports on $CCO_2$ while imports, and economic growth significantly have positive impact on $CCO_2$

The cooperation between two or more public and private sectors typically of a long term nature either for production or service as a form of public-private partnership in energy. Shahbaz et al. (2020) investigated the public-private partnerships investment in energy as the new determinant of carbon emissions considering the role of technological innovations. It was discovered that increased public-private partnership investments in energy and foreign direct investments in the consumption of energy disrupts environmental quality and depreciates the environment by contributing immensely to the level of carbon dioxide emissions. Technological innovations harm carbon dioxide emissions. Additionally, Zeeshan et al. (2020b) employed several econometric methods (generalized least square, Maki cointegration test, fully modified ordinary least square, dynamic ordinary least square, canonical cointegration regression, and frequency domain causality test) to estimated the effect of public- private partnership investment in energy and technological innovation on consumption- based carbon emissions for China. While the study showed that tehnological innovation abate the $CCO_2$ emissions, it also revealed that public- private partnership investment in energy upsurge the $CCO_2$ emissions. In summary, the findings suggested that technological innovation is required for china to produce cleaner production process, and that investing in renewable energy by public- private partnership could lower the emissions. It is therefore important to concentrate efforts towards technological innovations and public- private partnership imvestment that encourage environmental quality.

### 2.1.3 Other determinants of carbon emission

Generally speaking, the usage of electricity or carrying out commercial, industrial, and economic activities are usually associated with energy consumption. However, issues like financial development, tourism, urbanization, agriculture production – resulting from the use of energy, also serve as drivers for carbon emissions. Travelling for pleasure or business purposes to other countries particularly in form of tourism is a major determinant of economic development and one of the determinants of the foreign population thus increased energy demand and consumption. Wu et al. (2015) conducted a measure and comparative study of carbon dioxide emissions from tourism. It was discovered that total emissions from tourism increased continuously and this has made it imperative for the government to promote energy conservation and emissions reduction through formulating implementation guide, energy conservation technology innovation, enhancing the awareness on environmental protection as well as the cooperation of regional tourism. Further, estimating emissions from tourism activities, Russo et al. (2020) found tourism to contribute to carbon emissions even in areas with existing environmental degradation. This may be associated with the increased economic activities caused by tourism inflows.

Progressively, agriculture and agricultural production have more than doubled since 1970 and emissions from agriculture also increased. Although recent developments in agriculture processes have led to a reduction in agriculture-related carbon emissions. Bennetzen et al. (2016) analysed the major agricultural production and greenhouse gas emissions trend in the world for over 40 years. It was discovered that efforts have been made to minimize agriculture-based carbon emissions and for most countries, generally, intensive and industrialized systems show the lowest emissions per unit of agriculture production in countries of the world. Waheed et al. (2018) analysed the relationship between forest, agriculture, renewable energy and carbon dioxide emissions. It was discovered that in the long run, renewable energy consumption and forest exerts negative ad significant impact on carbon emission, that is, both renewable energy and forest contribute majorly to mitigating carbon emissions. On the other hand, agricultural production positively and also significantly affects carbon emissions in the long run which mean that increased agricultural production contributes to increasing carbon dioxide emissions. It is important to note that forest planting is more effective towards carbon dioxide emissions reduction compared to renewable energy and agriculture.

Last but not the least, Khan et al. (2019) in their findings established a different relationship between the variables for the different countries considered. In Asia and America, a one-way causal link exists between financial development and greenhouse gases. The same relationship exists between trade openness and greenhouse gases and between tourism and greenhouse gases in Asia Europe and America. Also, tourism has a one-way causal link with renewable energy in Europe. It has become necessary to fix the compulsory target of renewable energy by establishing a separate agency for renewable energy. This will imply deliberate effort towards reducing carbon emissions and encouraging renewable energy consumption in replacement of non-renewable energies.

## 2.2 Theoretical Framework

Simon Kuznets (1955) established this theory, which is premised on the income disparity known as the Kuznets curve. Kuznets (1955) analyzed the trend of increasing per capita income and disparity. There is a turning point in the curve, which reveals that rural farmers' per capita income who leave their agricultural practices to take up professional employment in urban cities is gradually rising, which closes the large distance between the rich and the poor. At this junction, the income disparity difference is projected to decline, increasing the poor farmers' per capita income. Environmental economists such as Panayotou (1997) and Grossman & Krueger (1991)) utilized this theory to explore the interconnection between ecological deterioration and economic expansion. According to them, growth in the economy happens in three distinct phases, namely: scale effect, structural and composite effects. In the early phase of development, the ecosystem will struggle before a certain point (the turning point) is reached; economic expansion will deteriorate environmental quality at this stage. The early phase is known as the scale effect phase, whereas the structural and composite effect phases are the turning-point and the period after the turning point. The scale effect phase is linked with emerging countries where non-renewable energy sources back the economy's performance and production activities. In contrast, the structural and composite effect phases are linked with industrialized economies where technological innovation and services dominate economic performance.

# 3. Methodological Foundation

## 3.1 Background and Descriptions of Data

This study investigates the impact of economic growth (GDP), electricity consumption (ELE), technological innovation (TI), renewable energy consumption (REN) and public-private partnership investment in energy (PPIE) on consumption-based carbon emissions ($CCO_2$) from 1990 to 2018 in Brazil. The variables utilized are transformed into their natural logarithm. This was conducted to make the series conform to normality (Awosusi et al. 2020; Onyibor et al. 2020; Odugbesan & Adebayo, 2020; Kirikkaleli et al. 2020; Balsalobre-Lorente et al. 2020). Table 1 illustrates the data source, measurement, and unit of measurement. Furthermore, Figure 1 illustrates the trends of the variables utilized between 1985 and 2018. Also, the flow of analysis is depicted in Figure 2. The study economic function is depicted in Equation 1:

$$CCO_{2t} = f(GDP_t, PPIE_t, REN_t, ELE_t\ TI_t) \quad [1]$$

In Equation 1, PPIE, GDP, REN, $CCO_2$, TI and ELE represents public-private partnership investment in energy, economic growth, renewable energy, electricity consumption and technological innovation. The study economic model and econometric model are depicted as follows in Equation 2 and 3 respectively as follows.

$$CCO_{2t} = \vartheta_0 + \vartheta_1 GDP_t + \vartheta_2 PPIE_t + \vartheta_3 REN_t + \vartheta_4 ELE_t + \vartheta_5 TI_t + \varepsilon_t \quad [3]$$

In this study, the aim of using $\mathrm{GDP_t}, \mathrm{PPIE_t}, \mathrm{REN_t}, \mathrm{ELE_t}$ and $\mathrm{TI_t}$ are stated as here. Over the decades, numerous researches have been conducted on these interconnections (Bekun et al. 2019; Lin & Zhu, 2019; Adebayo & Odugbesan 2020; Kirikkaleli et al. 2020; Balsalobre-Lorente et al. 2020; Fernández et al. 2018; Wang et al. 2020; Alola et al. 2019; Saint et al. 2019; Adedoyin et al. 2020). Nonetheless, all these investigators do not take into account consumption-based carbon emission in their investigations. As stated by Knight & Schor, (2014), Khan et al. (2020), Safi et al. (2020) and Shahbaz et al. (2020), $CCO_2$ is essential because it not only takes the global supply chain into account but also contributes to the creation of emissions and distinguishes between pollutants created in one country and used in another. In line with the study of Adebayo (2020), Kirikkaleli et al. (2020), Balsalobre-Lorente et al. (2020), and Alola et al. (2019), GDP is introduced into the framework. The interconnection between GDP and environmental pollutions is expected to be positive. This implies that an increase in GDP would deteriorate the quality of the environment i.e. $(\beta_1 = \frac{\partial CCO_2}{\partial GDP} > 0)$. Following the study of Shahbaz et al. (2020), Khan et al. (2020), and Anwar et al. (2020), public-private investment in energy was incorporated into the framework. An increase in public-private investment in energy would exert a negative impact on environmental degradation. Hence, public-private investment in energy is anticipated to enhance the quality of the environment, i.e. $(\beta_2 = \frac{\partial CCO_2}{\partial PPIE} < 0)$. Also, following Shahbaz et al. (2020), Khan et al. (2020), Alola et al. (2019) and Saint et al. (2019), renewable energy is introduced into the model. Renewable energy is expected to exert a negative impact on environmental degradation. This implies that renewable energy would improve environmental quality i.e. $\left(\beta_3 = \frac{\partial CCO_2}{\partial REN} < 0\right)$. In line with the study of Saint Akadiri et al. (2020), Rahman (2020), Salahuddin et al. (2018), and Kahouli, (2018) we incorporate electricity consumption into our model. Electricity consumption is expected to exert a positive impact on environmental degradation. This implies that electricity consumption will harm the quality of the environment, i.e. $\left(\beta_4 = \frac{\partial CCO_2}{\partial ELE} > 0\right)$. We also explore the interconnection between technological innovation and environmental degradation. As stated by Khan et al. (2020) and Shahbaz et al. (2020) technological innovation would enhance the quality of the environment. Thus, technological innovation is expected to exert a negative impact on environmental degradation, i.e. $\left(\beta_5 = \frac{\partial CCO_2}{\partial TI} < 0\right)$.

**Table 1: Variables Units and Sources**

| Variable | Description | Units | Sources |
|---|---|---|---|
| $CCO_2$ | Consumption-Based Carbon Emissions | Million tons of $CO_2$ emissions | GCA by Peters et al. (2011) and Gilfillan et al. (2019) |
| GDP | Economic Growth | GDP Per Capita Constant $US, 2010 | Word Development Indicators (WDI, 2020) |
| PPIE | Public-Private Partnerships Investment In Energy | Public-private partnerships investment in energy (current US$) | https://databank.worldbank.org/source/world-development-indicators#advancedDownloadOptions |
| TI | Technological Innovation | Measured as the addition of Patent applications, residents and Patent applications, non-residents | |
| REN | Renewable Energy | Renewables per capita (kWh) | BP (2020) https://ember-climate.org/data/ |
| ELE | Electricity Consumption | Measured in kilowatts per hour, | |

**Source:** Authors Compilation

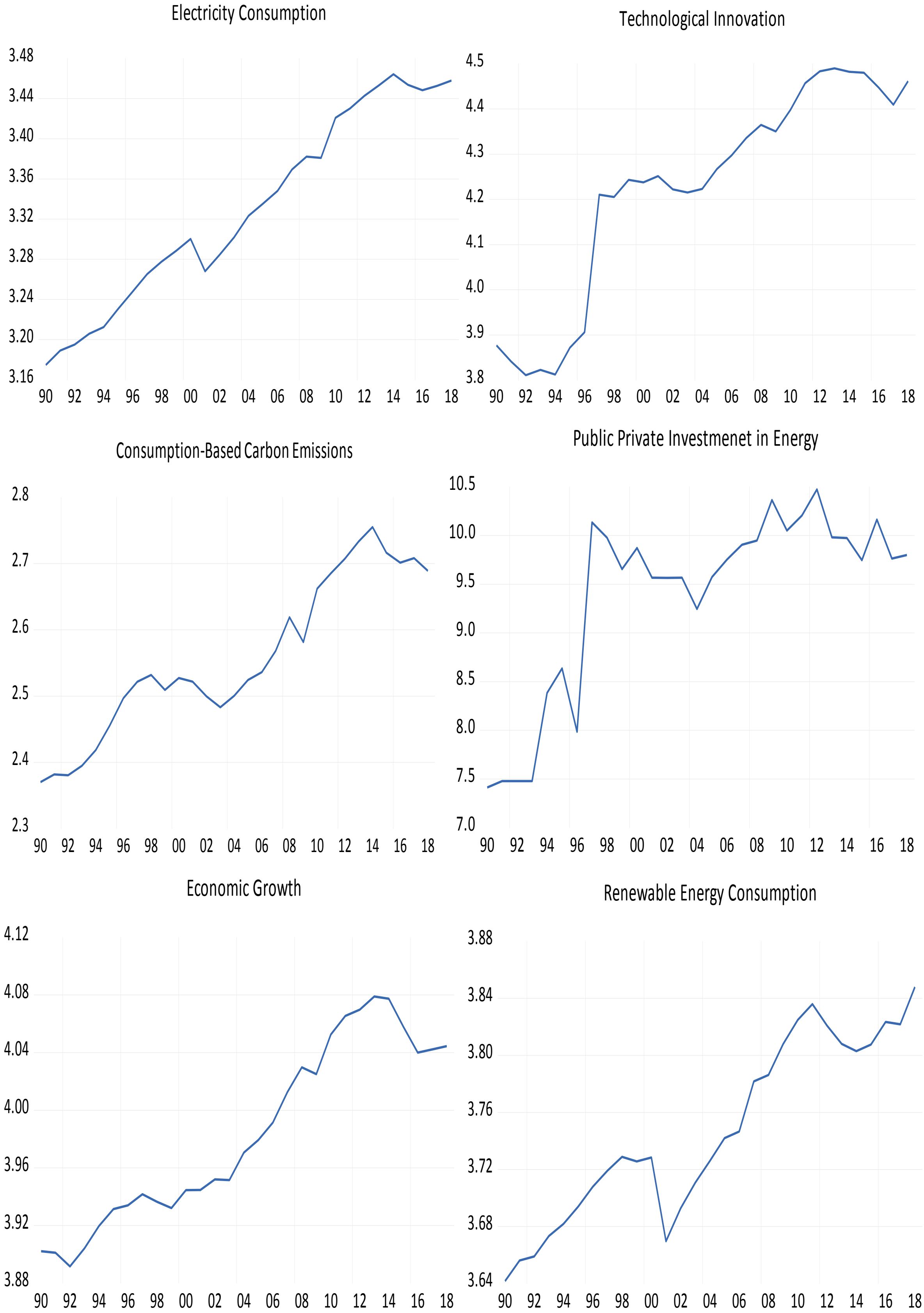



**Figure 1: ELE, TI, $CCO_2$, PPIE, GDP and REN in Brazil**

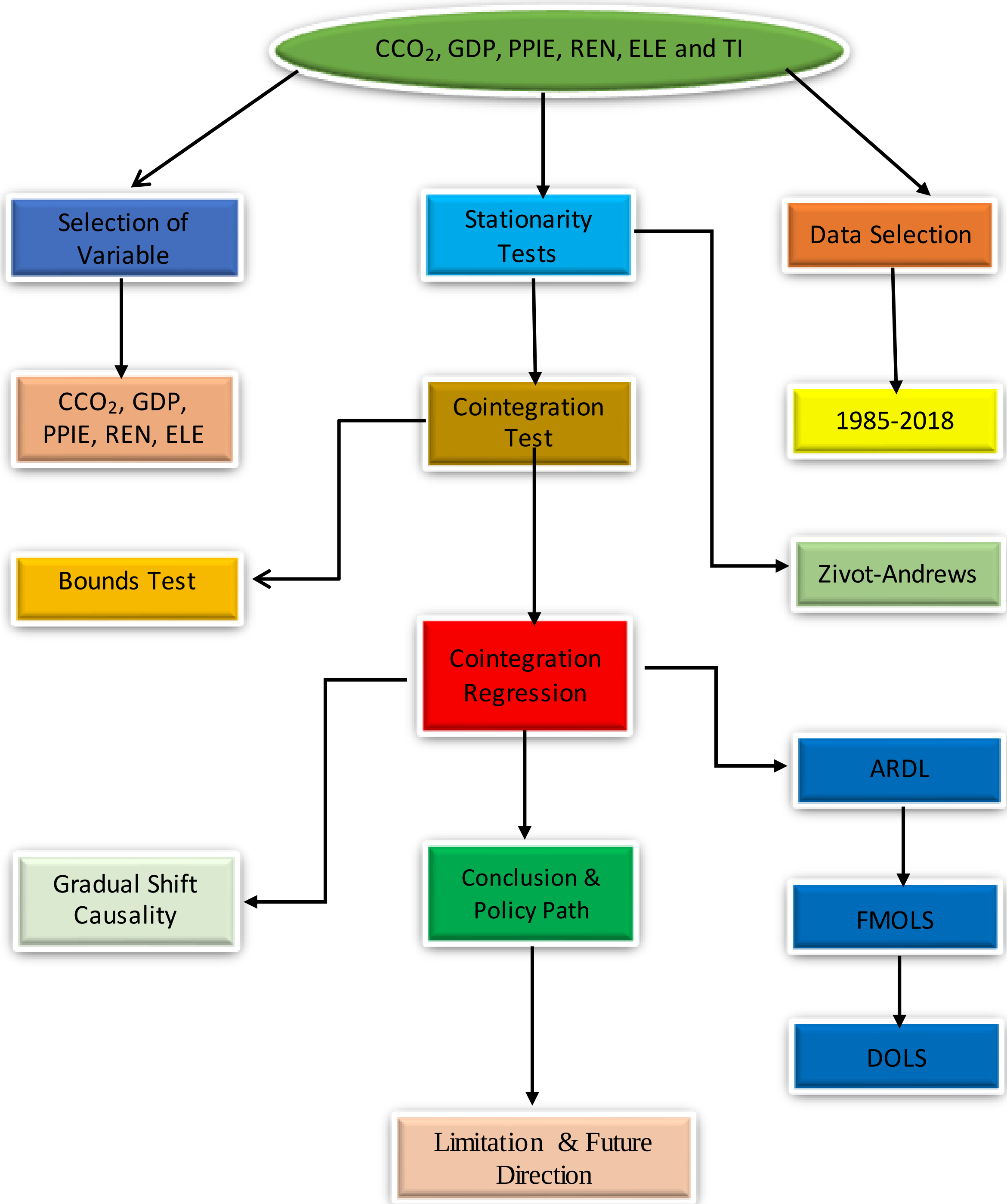



**Figure 2: Flow Chart**

## 3.2 Methodology

### 3.2.1. Unit Root Test

The traditional unit-root tests including Augmented Dickey-Fuller (ADF) and Phillips and Perron (PP) cannot be utilized if there is the existence of structural break(s) in a time series data due to unauthentic and prejudiced outcomes which may result to null hypothesis rejection disproportionately (Beton & Adebayo, 2020; Khan et al. 2020; Saint Akadiri et al. 2020; Rahman, 2020; Adebayo & Beton, 2020). Thus, we employed the Zivot and Andrew unit root test proposed by Zivot and Andrews (2002) to catch both single break and stationarity properties simultaneously. The following Equations depict the Zivot and Andrew (2002) unit root test:

$$\Delta x_t = \varphi + \varphi x_{t-1} + \pi t + \delta DU_t + \sum_{j=1}^{k} d_j \, \Delta x_{t-j} + \mu_t \qquad [4]$$

$$\Delta x_t = \varphi + \varphi x_{t-1} + \pi t + \gamma DT_t + \sum_{j=1}^{k} d_j \, \Delta x_{t-j} + \mu_t \qquad [5]$$

$$\Delta x_t = \beta + \beta x_{t-1} + \beta t + \theta DU_t + \theta DT_t + \sum_{j=1}^{k} d_j \, \Delta x_{t-j} + \mu_t \qquad [6]$$

There are three options when implementing the Zivot-Andrews unit root test. They are; at intercept, trend and intercept and trend. The preceding model can be captured. Where the dummy variable is depicted by $DU_t$, which demonstrates a shift occurred at a breakpoint. The trend in shift is illustrated by $DT_t$. The empirical analysis utilizes model 6.

Therefore,

$$DU_t = \begin{cases} 1 \ldots\ldots if \;\; t > TB \\ 0 \ldots\ldots if \;\; t < TB \end{cases} \text{ and } DU_t = \begin{cases} t - TB \ldots.if \;\; t > TB \\ 0 \ldots\ldots \quad if \;\; t < TB \end{cases} \qquad [6]$$

The null hypothesis of unit root break date is $\beta = 0$ which implies non-stationary with a drift that does not have structural breakpoint information, whereas the alternative hypothesis is $\beta < 0$ which demonstrates stationary with one unidentified time break.

### 3.2.2 Cointegration

This current study utilized the ARDL bounds test to capture the cointegration amongst the series. Pesaran et al. (2001) bounds test is preferred to other cointegration tests due to the following reasons. Firstly, it can be utilized when series are integrated at mix order; secondly, it is significantly more reliable, particularly for small sample size (Akinsola

& Adebayo, 2021), and thirdly, it offers accurate estimations of the long-term model. The Bounds test follows the F-distribution, and its critical values are initiated by Pesaran and Timmermann (2005). The ARDL bounds test is depicted as follows in Equation 4;

$$\Delta CCO_{2t} = \vartheta_0 + \beta_1 CCO_{2t-1} + \beta_2 GDP_{t-1} + \beta_3 PPIE_{t-1} + \beta_4 REN_{t-1} + \beta_5 ELE_{t-1} + \beta_6 TI_{t-1} + \sum_{i=1}^{t} \vartheta_1 \Delta CCO_{2t-i} + \sum_{i=1}^{t} \vartheta_2 \Delta GDP_{t-i} + \sum_{i=1}^{t} \vartheta_3 \Delta PPIE_{t-i} + \sum_{i=1}^{t} \vartheta_4 \Delta REN_{t-i} + \sum_{i=1}^{t} \vartheta_5 \Delta ELE_{t-i} + \sum_{i=1}^{t} \vartheta_5 \Delta TI_{t-i} + \varepsilon_t \quad [7]$$

The null hypothesis and the alternative hypotheses are no co-integration and evidence of co-integration, respectively. We reject the null hypothesis if the F-statistics is more than the lower and upper bond critical values. Equations 8 and 9 illustrate the null and alternative hypotheses correspondingly;

$$H_0 = \vartheta_1 = \vartheta_2 = \vartheta_3 = \vartheta_4 = \vartheta_5 = \vartheta_6 \quad [8]$$

$$H_a \neq \vartheta_1 \neq \vartheta_2 \neq \vartheta_3 \neq \vartheta_4 \neq \vartheta_5 \neq \vartheta_6 \quad [9]$$

Where $H_0$ denotes the null hypothesis and $H_a$ illustrates the alternative hypothesis.

The study utilizes the criteria of Kripfganz and Schneider (2018) which requires the generated T-statistics and F-statistics to be higher than the corresponding upper critical values, an essential requirement for deciding on cointegration, unlike the prior decision-making criteria that demand the F-statistic higher than the upper critical values for cointegration. Also, the p-values produced should be below the target levels.

### 3.2.3 ARDL Approach

After cointegration among the parameters is confirmed, the study utilized the ARDL approach. After the long-term linkages have been identified, short-term interconnections are investigated using the Error Correction Model (ECM) developed by Engle and Granger (1987) for the assessment of short-term coefficients and the Error Correction Term (ECT). This is done by integrating the ECM into the ARDL framework for Model 5 as follows;

$$\Delta CCO_{2t} = \vartheta_0 + \sum_{i=1}^{t} \vartheta_1 \Delta CCO_{2t-i} + \sum_{i=1}^{t} \vartheta_2 \Delta GDP_{t-i} + \sum_{i=1}^{t} \vartheta_3 \Delta PPIE_{t-i} + \sum_{i=1}^{t} \vartheta_4 \Delta REN_{t-i} + \sum_{i=1}^{t} \vartheta_5 \Delta ELE_{t-i} + \sum_{i=1}^{t} \vartheta_5 \Delta TI_{t-i} + \rho ECT_{t-i} + \varepsilon_t \qquad [7]$$

Where the speed of adjustment is depicted by $\rho$ and the error correction term depicted by $ECT_{t-1}$.

### 3.2.4 Long-run Estimators

To verify the outcomes of the ARDL long-run estimates, we employ the FMOLS and DOLS tests. While various econometric approaches can be used to evaluate the long-run interconnection between variables, the Fully Modified OLS (FMOLS) introduced by Phillips and Hansen (1990) and the Dynamic OLS approach developed by Stock & Watson (1993) were used in this analysis. These methods permit asymptotic coherence to be obtained by considering the impact of serial correlation. FMOLS and DOLS can only be done if there is proof of co-integration between the series. Therefore, long-term elasticity with FMOLS and DOLS estimators is calculated in this study.

### 3.2.5 Gradual Shift Causality Approach

The study utilized the Gradual shift causality test to explore the causal linkage between series. The Gradual shift causality test is preferred to the conventional Granger Causality test because it can be implemented for both I(0), and I(1) series. Furthermore, if there is evidence of co-integration between series, the Gradual shift causality test can still be applied. Due to the inability of the Toda-Yamamoto to take into consideration the effect of structural, Nazlioglu et al. (2016) introduced the gradual shift causality test. This test takes into account the effect of the structural break (s) when estimating causality analysis.

## 4. Empirical Findings and Discussions

This study investigates the impact of renewable energy usage, economic growth, electricity consumption, technological innovation, public-private partnership investment in energy on consumption-based carbon emissions from 1990 to 2018 in Brazil. Table 2 illustrates the statistical summary and different normality tests utilized. Furthermore, the series mean, median, mode, maximum, and minimum are revealed by the descriptive statistics. The study utilized Kurtosis to ascertain whether the variable is light-tailed or heavy-tailed relative to normal distribution. The empirical outcomes show that all the parameters are Platykurtic since their values are less than 3 with the exemption of PPIE. The value of skewness in all the variables also revealed that variables are moderately skewed. Furthermore, our study utilized the Jarque-Bera (JB) to test the parameters' normality features. The findings from the Jarque-Bera (JB) p-value revealed that all the indicators used in this empirical analysis conform to normality with the exemption of PPIE.

**Table 2: Descriptive Statistics**

| | $CCO_2$ | GDP | PPIE | ELE | REN | TI |
|---|---|---|---|---|---|---|
| Mean | 374.51 | 9725.44 | 7.12E+09 | 2194.5 | 5646.61 | 18898.2 |
| Median | 336.80 | 9346.03 | 5.65E+09 | 2105.6 | 5356.0 | 17849.0 |
| Maximum | 569.20 | 11993.4 | 2.97E+10 | 2912.4 | 7046.4 | 30884.0 |
| Minimum | 234.53 | 7791.7 | 25900000 | 1495.4 | 4382.4 | 6474.0 |
| Std. Dev. | 102.38 | 1392.8 | 7.11E+09 | 479.09 | 819.83 | 8350.8 |
| Skewness | 0.4290 | 0.2646 | 1.460718 | 0.1775 | 0.1488 | -0.1320 |
| Kurtosis | 1.8792 | 1.5784 | 5.166768 | 1.6027 | 1.6226 | 1.8280 |
| Jarque-Bera | 2.4074 | 2.7803 | 15.98585 | 2.5115 | 2.3992 | 1.7438 |
| Probability | 0.3000 | 0.2490 | 0.000338 | 0.2848 | 0.3013 | 0.4181 |

It is vital to ascertain the order of integration in time-series before further analysis is conducted. Furthermore, it is well established, traditional unit-root tests often reject the null hypothesis of unit root disproportionately. Though many conventional unit-root tests are utilized to ascertain the stationarity characteristics of variables, however, they are excluded in this paper because Akinsola and Adebayo (2021), Bekun et al. (2019), Balsalobre-Lorente et al. (2020), Kirikkaleli et al. (2020) and Shahbaz et al. (2020) claimed that they yield ambiguity and erroneous outcomes due to structural break(s) in the variables. Therefore, we employed a unit root test that can identify a single break in the parameters. Based on this, the paper utilized the Zivot-Andrew unit root test to capture the series stationarity features in the presence of a structural break. Table 3 illustrates the results of the unit root test. The empirical findings from the test revealed that GDP, TI and PPIE are stationary at level. However, after taking the first difference, i.e. I(1), all the series are stationary.

**Table 3: Zivot and Andrews Unit root Test**

| | At Level I(0) | First Difference I(1) |
|---|---|---|

| | Intercept & Trend | Break-Date | Intercept & Trend | Break-Date |
|---|---|---|---|---|
| $CCO_2$ | -4.150 | 2003 | -6.322* | 2010 |
| GDP | -5.088*** | 2008 | -5.351** | 2004 |
| PPIE | -6.744* | 1997 | -8.101* | 2003 |
| REN | -3.519 | 2001 | -6.013* | 2000 |
| ELE | -3.697 | 2010 | -6.576* | 2010 |
| TI | -6.424* | 1997 | -6.505* | 1999 |

Note: *, ** and represents 1% , 5% and 10% level of significance

The study utilized the bounds test to capture the cointegration among PPIE, GDP, CCO2, TI, REN and ELE in Brazil between 1990 and 2018. The findings of the bounds test are reported in Table 4. The outcomes from the Table revealed that both F and T statistics are greater than Kripfganz and Schneider's (2018) critical value at a significance level of 1%. Thus, we confirm that all the variables are cointegrated in the long run. Furthermore, we conduct several post estimations tests to ascertain the reliability of the model. The outcomes of the post estimation tests are presented in Table 4. The results reveal that there is no evidence of serial correlation, misspecification, heteroscedasticity and residuals are normally distributed. The results of the CUSUM and CUSUM SQ in Figures 4a and 4b also show that the model is stable at a significant level of 5%.

**Table 4: ARDL Bound Test**

| Model | F-statistics | T-Statistics | $\chi 2$ ARCH | $\chi 2$ RESET | $\chi 2$ Normality | $\chi 2$ LM | |
|---|---|---|---|---|---|---|---|
| | 6.05* | -5.41* | 0.377 (0.95) | 1.55 (0.45) | 0.01 (0.99) | 1.488 (0.25) | |
| Kripfganz and Schneider (2018) critical and P-values | | | | | | | |
| | 10% | | 5% | | 1% | | PV |
| F-statistics | 2.204 | 3.320 | 2.615 | 3.891 | 3.572 | 5.112 | 0.00 |
| T-Statistics | -2.495 | -3.798 | -2.843 | -4.207 | -3.54 | -5.021 | 0.00 |

Note: Note * represent a 1% level of significance and PV denotes probability value both F-stat and T-stat are greater than critical values.

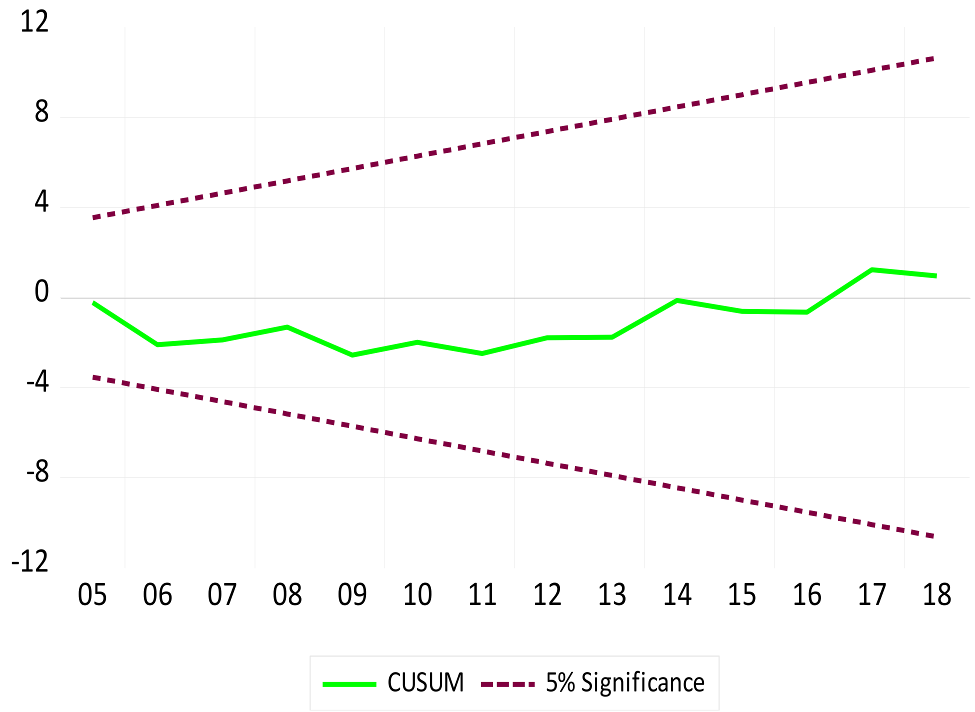



**Figure 4a:** CUSUM

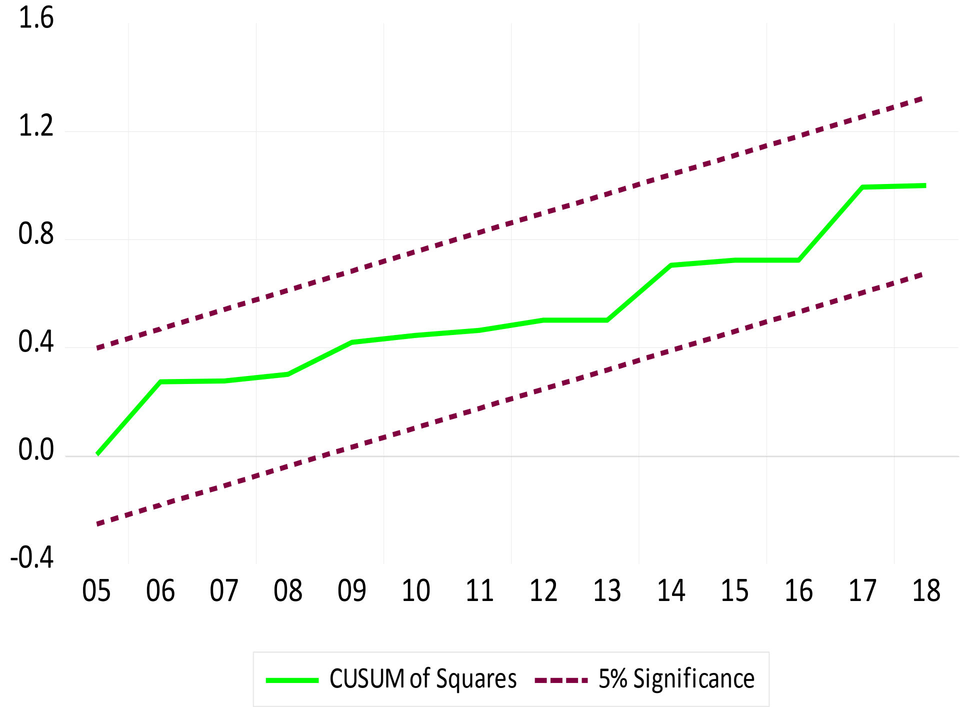



**Figure 4b:** CUSUMsq

After the long-run cointegration among the parameters is established, the study utilized the ARDL long-run and short-run estimations to ascertain the effect of economic growth, electricity consumption, technological innovation, public-private partnership investment in energy and renewable energy usage on consumption-based carbon emissions from 1990 to 2018 in Brazil. Appropriate Lag selection is essential when applying the ARDL. Thus, we utilized the AIC criteria proposed by Akaike (1987). Akinsola and Adebayo (2021) stated that the AIC is superiority over other criteria in the following ways; it displays better small sample features (Zhang et al. 2021). The results of the ARDL model is portrayed in Table 5. The values of the $R^2$ and adjusted $R^2$ are 0.99 and 0.98 correspondingly. This outcome illustrates that the regressors (PPIE, GDP, TI, REN and ELE) can explain 99% variation in $CCO_2$ while the remaining 1% variation is attributed to the error term. The results of the ARDL long-run and short-run estimations are depicted in Table 5. As seen, economic growth exerts a positive impact on $CCO_2$ which implies that increase in economic growth harm the quality of the environment. Therefore a 0.69% increase in $CCO_2$ is due to a 1% increase in economic growth by keeping other indicators constant. This outcome corresponds with the findings of Khan et al. (2020) and Shahbaz et al. (2020) who established a positive linkage between $CCO_2$ emissions and economic growth. The cause for the positive effect of economic growth on environmental pollutions is that the key sources for industry and agriculture are fossil fuels, which trigger both environmental degradation and growth in the economy (Kirikkaleli et al. 2020; Shahbaz et al. 2020). The rise in environmental pollution is attributed to the fact that industrial growth in Brazil is linked to the expansion of infrastructure, the development of trade and economic capitalization that has a positive impact on investment and economic production and thus raises energy use (Odugbesan & Adebayo, 2020). Also, systemic economic shifts, including the transformation from rural to industrial activities, can be mainly ascribed to this effect (Koengkan et al. 2019). Another potential cause for this effect is that an increase in economic development would lead to an increase in environmental deterioration at high-income levels due to the rise in the industrial sectors.

Table 5 also reports that public investment in energy exerts a negative impact on $CCO_2$ emissions which illustrates that an upsurge in PPIE would decrease environmental sustainability. Thus, a 1% increase in Public investment in energy would enhance the quality of the environment by 0.016% when other indicators are held constant. This implies public investment in energy enhances environmental quality in Brazil. This outcome refutes the findings of Shahbaz et al (2020) for China and Khan et al. (2020) for China who established that PPIE deteriorates the quality of the environment. As anticipated, there is a negative interconnection between renewable energy and $CCO_2$ emissions which infers that increase in renewable energy consumption mitigate environmental degradation in Brazil. Therefore, keeping other factors constant, a 0.452% decrease in environmental degradation is caused by a 1% increase in renewable energy. This illustrates that renewable energy usage improves the quality of the environment. This may be due to an increase in investment in renewable energy in Brazil. Moreover, the likely reason for the negative interconnection between consumption-based carbon emissions and renewable energy is due to investment in renewable energy. According to Bp (2020), more than US$ 36.6 billion was invested in the renewable energy sector in Brazil between 2014 and 2019. This result aligns with the prior studies (Shahbaz et al. 2020; Khan et al. 2020). In line with the expectation of the study, the interconnection between electricity consumption and cnonsumption-based carbon emissions is positive which implies that keeping electricity consumption deteriorate the quality of the enviironment. Thus, a 1% increase in electricity consumption would deteriorate the quality of the environment by 0.62% when other indicators are held constant. This shows that Brazil is on her growth trajectory. Moreover, the result shows that despite attempts to expand the usage of renewable resources in the energy sector, particularly in the field of electricity generation, substantial emission reductions are still far from real in Brazil. Finally, Table 5 shows that technological innovation exerts a negative impact on consumption-based carbon emissions which illustrates that an upsurge in technological innovation will decrease environmental degradation in Brazil. This illustrates that keeping other factors constant, a 0.11% decrease in environmental degradation is caused by a 1% increase in technological innovation. This illustrates that technological innovation decrease environmental degradation. The reason behind this linkage is that emissions incorporated in imported goods and exported goods minus production-based emissions are known as consumption-based carbon emissions. Thus, improvements in technology, therefore, tend to minimize it, both on the production and consumption side.

**Table 5: ARDL Results**

| Long-Run Results | | | |
|---|---|---|---|
| Regressors | Coefficient | T-stat | P-Value |
| GDP | 0.6799** | 2.5615 | 0.0182 |
| PPIE | -0.0164** | -2.4190 | 0.0247 |
| REN | -0.4525* | -3.1800 | 0.0045 |
| ELE | 0.6245** | 2.3654 | 0.0277 |
| TI | -0.1164** | -2.7518 | 0.0119 |
| $R^2$ | | 0.99 | |

| | | | |
|---|---|---|---|
| Adj $R^2$ | 0.98 | | |
| Short-Run Results | | | |
| GDP | 0.6799* | 4.7129 | 0.0001 |
| PPIE | -0.0164* | -4.4761 | 0.0002 |
| REN | -0.4525* | -4.7024 | 0.0001 |
| ELE | 0.6245* | 3.8067 | 0.0010 |
| TI | -0.0984* | 3.2746 | 0.0036 |
| ECM | -0.1798* | -6.2973 | 0.0000 |

Note: * and ** represents 1% and 5% level of significance

The study utilized the FMOLS and DOLS estimators as a robustness check to verify the findings of the ARDL long-run estimate. The results of the FMOLS and DOLS are presented in Table 6. The empirical outcomes show that PPIE, REN and TI enhance environmental quality while GDP and ELE deteriorate the quality of the environment. The results of the FMOLS and DOLS correspond with the findings of the ARDL long-run estimate.

**Table 6: FMOLS and DOLS Estimators**

| | FMOLS | | DOLS | |
|---|---|---|---|---|
| Regressors | Coefficient | T-stat | Coefficient | T-stat |
| GDP | 0.6775 | 5.8930* | 0.6799 | 3.2432* |
| PPIE | -0.0182 | -5.9890* | -0.0164 | -3.0628* |
| REN | -0.4420 | -6.7857* | -0.4525 | -4.0263* |
| ELE | 0.6135 | 5.2172* | 0.6245 | 2.9949** |
| TI | -0.1248 | -6.8569* | -0.1164 | -3.4842* |
| $R_2$ | 0.99 | | 0.99 | |
| Adj $R^2$ | 0.99 | | 0.99 | |

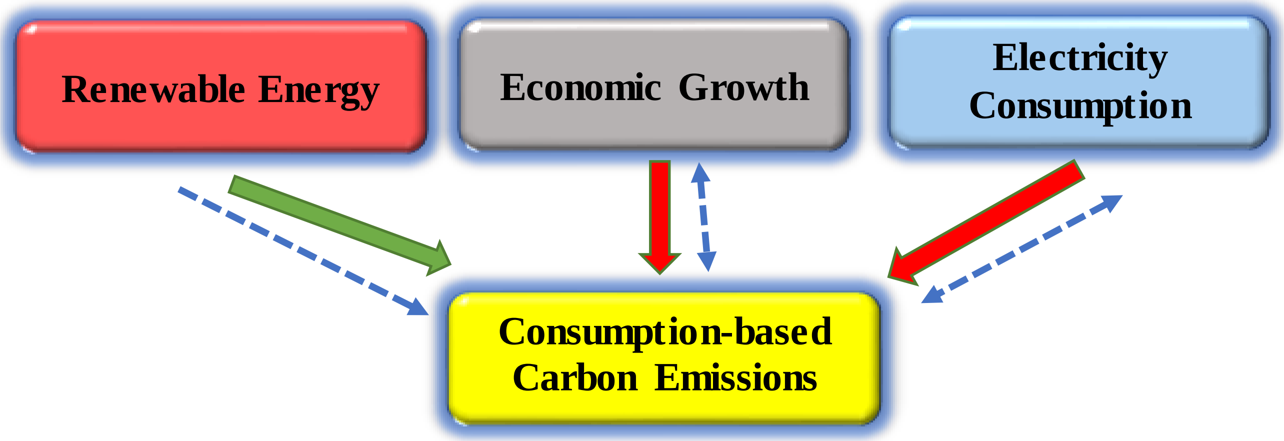
Note: * and ** represents 1% and 5% level of significance

To capture the causal impact of economic growth, electricity consumption, technological innovation, public-private partnership investment in energy and electricity consumption on consumption-based carbon emissions from 1990 to 2018 in Brazil, we employ the gradual shift causality test. Compared to other causality tests, the gradual shift causality test can capture causality between two series in the presence of structural break (s). The outcomes of the gradual shift causality test are reported in Table 7. The results show that; (a) there is a bidirectional causality between GDP and $CCO_2$ suggesting that both GDP and CCO2 can predict each other; (b) one-way causality running from PPIE to $CCO_2$ which demonstrates that PPIE can significantly predict $CCO_2$ emissios in Brazil. This outcome resonate the findngs of Kirikaleli and Adebayo, (2021) for India and Khan et al. (2020) for China; (c) feedback causality between ELE and $CCO_2$ which implies that both ELE and $CCO_2$ emissions can predict each other; (d) one-way causality from TI to $CCO_2$; and (e) unidirectional causality from REN to $CCO_2$.

**Table 7: Gradual Shift Causality Test**

| Causality Path | Wald-stat | No of Fourier | P-Value | Decision |
|---|---|---|---|---|
| $CCO_2$ → GDP | 17.742 | 1 | 0.0131** | Reject Ho |
| GDP → $CCO_2$ | 25.811 | 1 | 0.0005* | Reject Ho |
| $CCO_2$ → PPIE | 7.8832 | 1 | 0.3430 | Do not Reject Ho |
| PPIE → $CCO_2$ | 16.511 | 1 | 0.0208** | Reject Ho |
| $CCO_2$ → TI | 1.2580 | 1 | 0.9895 | Do not Reject Ho |
| TI → $CCO_2$ | 20.027 | 1 | 0.0055* | Reject Ho |
| $CCO_2$ →REN | 0.9166 | 3 | 0.9960 | Do not Reject Ho |
| REN → $CCO_2$ | 31.862 | 3 | 0.0000* | Reject Ho |
| $CCO_2$ → ELE | 14.664 | 4 | 0.0405** | Reject Ho |
| ELE→ $CCO_2$ | 36.164 | 4 | 0.0000* | Reject Ho |

Note: *, ** and *** represents 1%, 5% and 10% level of significance respectively



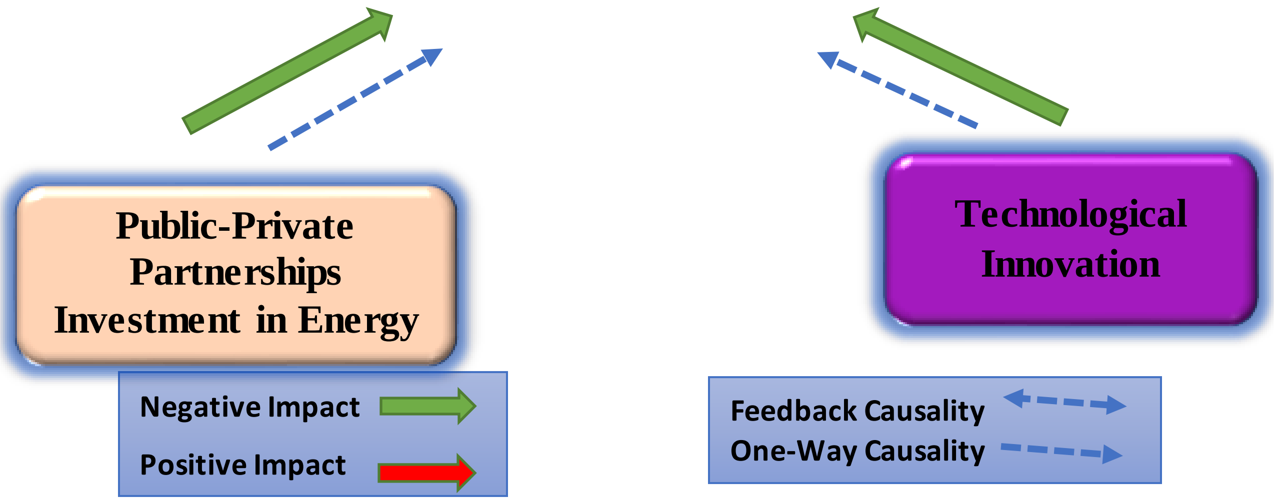



**Figure 5:** Graphical Findings

## 5. Conclusion and Policy Implications

Last few decades mirrors that one of the most important global problems in the world is global warming and climate change. Although Brazil signed the Kyoto protocol as well as the Paris agreement to control $CO_2$ emissions, Brazil is the sixth-largest emitter of greenhouse gases and the third largest emitter in the developing world after China and India. We explore the impact of renewable energy usage, economic growth, technological innovation, public-private investment in energy, and electricity consumption on consumption-based $CO_2$ emissions in Brazil. Based on the aim of the present study, ARDL bounds, FMOLS, DOLS and gradual shift causality tests are employed. As illustrated in Figure 5, the outcomes of this study reveal that while renewable energy usage, technological innovation and public-private investment in energy improve the environmental quality, electricity consumption and economic growth increase environmental degradation. The outcomes of the gradual shift causality approach also support the outcome of ARDL, FMOLS, and DOLS estimators.

The present study recommends that the government of Brazil should actively promote the research and development of low-carbon technologies while domestic consumption level should be targeted, especially those sectors which are more energy-intensive and causing to increase consumption-based $CO_2$ emissions. The implementation of environmentally responsive taxes and subsidies in specific sectors of the economy is another policy path for the Brazilian government. Pollution taxes should be imposed on sectors or industries that surpass a certain amount of pollution, whereas subsidies should be provided to industries or sectors that implement green, environmentally friendly technologies. The financial sector should be encouraged to channel credit facilities to industries or sectors that are able to follow environmentally friendly processes as a matter of policy. Brazil must also increase its involvement in the worldwide decarbonization effort. Moreover, investment in renewable energy consumption through public-private participation should be encouraged. Also, Brazil should carry on encouraging the use of the wind and solar energy in electricity production to reduce consumption-based $CO_2$ emissions in Brazil. Although the present study utilised recent econometric techniques to examine the impact of the renewable energy usage, economic growth, technological innovation, public-private investment in energy, and electricity consumption on consumption-based $CO_2$ emissions in the case of Brazil, unavailability of data beyond the period of study is the major setback in this empirical analysis. Further studies can be conducted for the other developin economies while considering asymmetric in the econometrics modelling or the use of micro disaggregated data.

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