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# Load Capacity Factor and Financial Globalization in Brazil: The Role of Renewable Energy and Urbanization

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To mitigate environmental challenges and fulfill the Sustainable Development Goals, a broader and holistic ecological assessment is required. As a result, this research utilizes the load capacity factor, which is a distinct proxy of environmental deterioration that offers a detailed environmental evaluation measurement by comparing biocapacity and ecological footprint simultaneously. Moreover, the load capacity factor provides the combined attributes of the demand and supply-side of environmental quality. Therefore, this research scrutinized the effect of financial globalization, urbanization, economic growth, and renewable and nonrenewable energy usage on load capacity factor for the period stretching between 1970 and 2017 in Brazil. The bounds testing procedure for cointegration in combination with the critical approximation *p*-values of Kripfganz and Schneider (2018) disclosed a cointegrating association between load capacity and its regressors. The outcome of the ARDL method uncovered that economic growth, non-renewable and renewable energy reduce the load capacity factor, whereas urbanization has no impact on load capacity factor in Brazil. However, financial globalization has a positive effect on load capacity factor in Brazil. Finally, the study uses the spectral causality test to assess the causality interaction between the observed parameters. The policymakers should take advantage of the opportunity by developing policies that encourage the openness of the economy to foreign investors.

**Keywords: load capacity, financial globalization, urbanization, renewable energy, Brazil**

## INTRODUCTION

Despite the public understanding of climate change and the process to mitigating it, global emissions including acidifying gases, ozone precursor gases, anthropogenic greenhouse gases (GHGs), and other environmental contamination sources have failed to decline dramatically (Sharif et al., 2021; Usman et al., 2021). However, environmental scientists and intergovernmental organizations around the globe have become more conscious of global warming and other facets of climate change in recent years, research has shown that the ongoing global danger to the climate and atmosphere remains a significant problem for humanity in the twenty-first century (Ayobamiji and Kalmaz, 2021; Oladipupo et al., 2021; Panait et al., 2021; Pata 2021). The International Energy Agency (2019) reports that the level of carbon dioxide ($CO_2$ emissions) rose by 1.7% in 2018, implying a new high of 33.1 gigatons (Gt) of equivalent $CO_2$ which accounts for the majority of GHGs. The rise in $CO_2$ emissions is related to global economic growth alongside higher utilization of energy (IEA, 2019) As a result, the UNFCC (United Nations Framework Convention on Climate Change) has continuously urged further committment to the 2015 Paris Agreement, particularly by state actors, in partnership with other stakeholders. In terms of pollution patterns, several industrialized nations, including the United Kingdom, Brazil, France, Japan, Germany, and Mexico, have announced significant committment towards the reductions in $CO_2$ emissions, whereas environmental degradation persists (EIA, 2020).

The discussion about the position of globalization toward environmental concerns in promoting economic growth is a recent subject matter. Particularly, in the globalized period, where developing and emerging nations improve the domestic economic structure by integrating trade, technology transfers, and financial activities; as a consequence, the growth of global economic activities may lead towards higher energy consumption and GHG emissions (Adebayo and Kirikkaleli, 2021; Xia et al., 2022; Olowu et al., 2021). Dreher (2006) constructed the globalization index, which is made up of political, social, and economic components. However, Gygli et al. (2019) improved this index by incorporating additional sub-indices for a deeper comprehension of this dynamic of globalization. For instance, economic globalization is often characterized as a blend of financial and trade components. As a result, it was impossible to differentiate between the environmental implications of trade globalization as well as financial globalization based on the computation of Dreher (2006). Whereas the recent computation of Gygli et al. (2019) offers us the opportunity to differentiate between the environmental implications of trade globalization as well as financial globalization. This study employed the financial globalization index, which is constituted of *de facto* and *de jure* aspects. The *de facto* aspect of financial globalization entails the reserves, international income payment, portfolio investment, international debt, and foreign direct investment, whereas the *de jure* components of financial globalization are agreement associated with investment and investment barriers. This index provides the opportunity to understand which economies are more globalized financially. In this regard, our study try to examine whether urbanization and financial globalization could help address the concern of economic expansion in emerging nations without generating environmental degradation. This current research aims to provide policy recommendations in the context of environmental degradation based on an examination of financial globalization, and renewable and nonrenewable energy usage.

However, several studies have been undertaken to scrutinize the influence of various economic and social determinants on carbon emissions (Odugbesan et al., 2021; Orhan et al., 2021; Su et al., 2021; Zhang et al., 2021). Meanwhile, Akinsola et al. (2021) argued that carbon emissions, which represent a large proportion of greenhouse gas emissions, are inadequate to represent and assess overall environmental deterioration. Based on this argument, Galli et al. (2012) argued that ecological footprint is one of the most extensive economic-ecological variables used to assess environmental degradation. Rees (1992) introduced the ecological footprint, which concurrently represents anthropogenic impacts on the ecosystem in the form of pollution on the land, sea, and air. The accounting of the ecological footprint comprises two different measurements--ecological footprints and biocapacity. Ecological footprint accounts for the demand side of nature in global hectares while biocapacity represents nature's supply-side in global hectares (Galli, 2015).

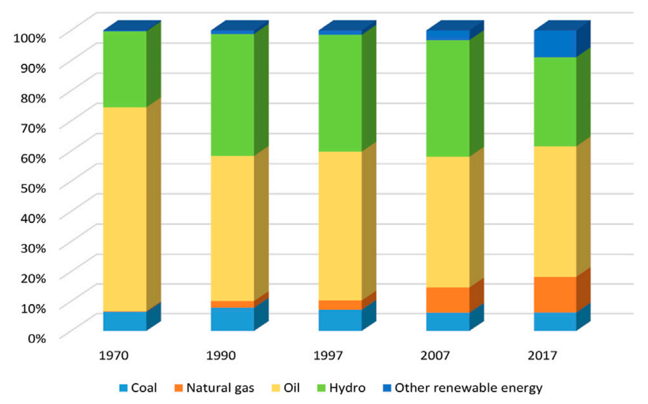


**FIGURE 1** | Share of different energy consumption source in Brazil.

Several studies have been undertaken to scrutinize the influence of various social and economic determinants on the ecological footprint for developed or developing economies (Ahmed et al., 2021; Danish et al., 2020; Adebayo and Rjoub, 2021; Caglar et al., 2021; Majeed et al., 2021). However, these studies are primarily concerned with the ecological footprint and completely disregard the ecosystem's supply side. Thus, there is a need to find a more adequate and correct measurement for evaluating the quality of the environment. Siche et al. (2010) suggested that load capacity factor is more accurate for environmental assessment. The load capacity factor indicates a nation's strength or ability to maintain its people in accordance with their contemporary lifestyles. To compute the load capacity factor, the supply side (biocapacity) is divided by the demand side (ecological footprint). Thus, when the load capacity factor is less than 1, this suggests that the condition of the ecosystem is unsustainable while when the load capacity factor is greater than 1, this shows that the ecosystem is sustainable (Pata et al., 2021). Therefore, the sustainability threshold is equivalent to one. Based on the premise of this argument, it is evident that the load capacity factor is a broader complete measurement than carbon emissions and ecological footprint. As a result, we perform a more detailed and extensive analysis, as opposed to earlier literature.

The rationale for choosing Brazil as the focus of the study is based on the following: Brazilian economy is valued at US$1.84

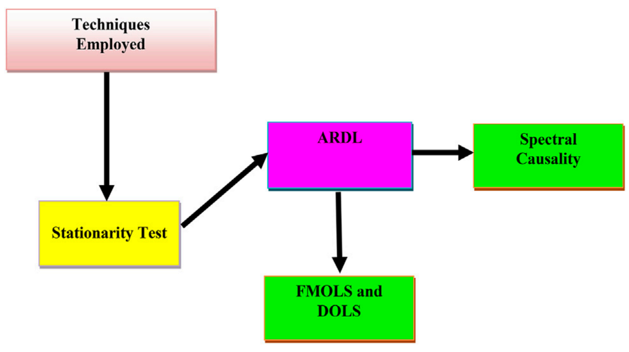


**FIGURE 2** | Graphical flow of analysis.

trillion in terms of GDP as well as the country's GDP per capita is valued at US$8717.19 (World Bank, 2021). This makes the economy one of the biggest in the South American region. Brazil is currently attracting higher foreign investments since the country is grouped along with the top five emerging economies (BRICS). For instance, the financial globalization index of Brazil to 64.49 points in 2017 from 39.27 points in 1970 makes the country one of the most globalized economies in the South American region. The country reliance on fossil fuel is huge (as seen in **Figure 1**) with natural gas, coal, and oil constituting 10.39, 5.29, and 38.14%, respectively, whereas renewable energy consists of the country's energy mix, which is hydro (28.70%), solar (0.40%), other renewable sources (4.04%), and wind (4.01%) for 2017. When it comes to adapting to global warming, Brazil seems to have a unique combination of circumstances. Since the Amazon Forest is situated in Brazil, thus, most significant pollutants in Brazil are the land-use change and forestry sector. Thus, the country is the sixth biggest emitter of GHGs globally and the level of the country's ecological reserve continues to decrease over the last decade. Brazil joined the Paris Agreement in September 2016 with the nation's NDC targets to decrease GHGs by 37% from 2005 levels by 2025. However, due to the current events surrounding Brazil, events such as the COVID-19 pandemic, economic crisis, political tensions have raised concerns about the development of the environment and energy reform is halting.

Concerning the preceding discussion, the aim of this current research is to probe into the impact of financial globalization, urbanization, economic growth, and renewable and nonrenewable energy usage on load capacity factor using the ARDL method for the dataset ranging between 1970 and 2017. The following are the major contributions of this current research to the body of energy and environmental literature: (1) This study is the first attempt for the case of Brazil to employ load capacity factor as the measure for environmental degradation. As a result, the research addresses environmental issues from the supply and demand sides. This indicator elevates sustainable environmental discussions to a different level. (2) There are scant studies that investigate the effect of financial globalization on environmental degradation. To resolve these shortcomings in the literature, the current study employs the ARDL approach. (3) To evaluate the cointegration analysis utilizing the bounds testing procedure as well as Kripfganz and Schneider (2018) critical values and approximate $p$-values. The advantage of utilizing this approach is that it considers both the T-statistic and the F-statistic when identifying the cointegrating association between the variables of interest. (4) The study employed the spectral causality test to assess the causal interaction between the load capacity factor and its determinants. This technique is unique in that it uncovers the causality relationship at multiple frequencies (low, middle, and long term).

The remaining sections of this study are compiled as follows: **Section 2** contains the synopsis of related studies. The data and methods are presented in **Section 3**, also the empirical framework was discussed in the section. **Section 4** portrays the findings and discussion and the conclusion is discussed in the fifth section of this study.

## LITERATURE REVIEW

This segment of this current study covers the investigation that has been undertaken on the linkage between non-renewable and renewable energy usage, economic growth, financial globalization, and urbanization on environmental deterioration.

### Economic Growth and Environmental Deterioration

Pata and Isik (2021) investigated the interconnection between load capacity factor and economic growth in China for the period from 1981 to 2017, applied the autoregressive lag model (ARDL) approach. The empirical outcome established a negative interaction between load capacity and economic growth. The study of Pata and Balsalobre-Lorente (2021) in Turkey using the dataset covering from 1965 to 2017 found a negative association between load capacity factor and economic growth. The study of Khan et al. (2021) conducted an empirical analysis in Turkey and found economic growth contributed to the ecological footprint over the period between 1985 and 2017. Considering the study of Akinsola et al. (2021) for the case of Brazil, they detected a positive interaction between the ecological footprint and the economic expansion. Using the asymmetric approach, Majeed et al. (2021) discovered a negative interaction between economic growth and ecological footprint in Pakistan over the period from 1971 to 2014. The study of Solarin et al. (2021) for the case of Nigeria, used the ARDL approach for the dataset covering from 1977 to 2016. They found a positive interaction between the ecological footprint and the economic growth. Adebayo et al. (2021) discovered a positive interrelationship between carbon emission and economic growth in South Korea for the period between 1965 and 2019. Awosusi et al. (2021) detected a positive interconnection between $CO_2$ emissions and economic growth in Japan covering from 1965 to 2019. Ramzan et al. (2021) detected a positive connection between $CO_2$ emissions and economic growth in Latin American nations.

## Energy Consumption and Environmental Deterioration

The study of Yuping et al. (2021) in Argentina covering the period between 1970 and 2018 found a positive association between non-renewable energy and $CO_2$ emissions, whereas the environmental quality of Argentina can be improved by renewable energy. Also, the research of Mohsin et al. (2021) for Asian economies affirmed that non-renewable and renewable energy has a positive and negative interaction on $CO_2$ emissions, respectively, for the period spanning between 2000 and 2016. Mahalik et al. (2021) discovered a positive relationship between $CO_2$ emissions and non-renewable energy in BRICS countries. Also, the authors found an adverse interaction between $CO_2$ emissions and renewable energy. Rjoub et al. (2021) conducted an empirical analysis on the G7 economies and found that the environmental quality can be improved by renewable energy over the period from 1985 to 2017. The investigation of Caglar et al. (2021) for 10 selected economies confirmed that there is a positive connection between non-renewable energy and ecological footprint; however, they also found an adverse interaction between renewable energy and ecological footprint. Likewise, Pata (2021) concluded that there is a positive interconnection between ecological footprint and non-renewable energy. Furthermore, the author also concludes that a negative interconnection between environmental degradation and renewable energy in the United States for the period between 1980 and 2016. The study of Bekun et al. (2021) in South Africa, used the ARDL method for the period between 1980 and 2017. They found no interaction between $CO_2$ emissions and renewable energy; however, non-renewable energy contributes to $CO_2$ emissions.

## Urbanization and Environmental Degradation

The study of Danish et al. (2020) reflected on the interaction between urbanization and ecological footprint using the Fully Modified Ordinary Least Square (FMOLS) and Dynamic Ordinary Least Square (DOLS) for BRICS countries. They found that urbanization reduces the ecological footprint. Nathaniel (2021) utilized the ARDL approach and discovered a positive association between the ecological footprint and urbanization in Indonesia for the period between 1971 and 2014. This study was also supported by the study of Nathaniel et al. (2019) in South Africa for the period between 1965 and 2014. However, the study of Nathaniel and Khan (2020) found a different outcome in the case of ASEAN economies. They found no interaction between ecological footprint and urbanization. Rafique et al. (2021) discovered a negative interaction between ecological footprint and urbanization in 10 selected economies for the period between 1980 and 2017. For the case of Nigeria, the research of Solarin et al. (2021) used the ARDL method for the period between 1977 and 2016. They found negative interaction between the ecological footprint and urbanization. Ahmed et al. (2020) also considered the interaction between the ecological footprint and urbanization in G-7 countries covering from 1971 to 2014. The empirical analysis showed a positive interconnection between the ecological footprint and urbanization. The study of Ansari et al. (2021) discovered a negative association between ecological footprint and urbanization in 22 selected countries. Abbasi et al. (2020) detected a positive interconnection between $CO_2$ emissions and urbanization in 8 Asian countries. Anser et al. (2020) discovered a U-shaped interconnection between $CO_2$ emissions and urbanization in SAARC (South Asian Association for Regional Cooperation). Zheng et al. (2021) detected a negative connection between $CO_2$ emissions and urbanization in China. Asongu et al. (2020) found a positive interaction between $CO_2$ emissions and urbanization employing the PMG-ARDL in 13 selected countries in Africa for the period between 1980 and 2014. Using the ARDL approach, the study of Prastiyo and Hardyastuti (2020) established that an increase in urbanization brings about the surge in $CO_2$ emissions in Indonesia.

## Financial Globalization and Environmental Degradation

Finally, the impact of financial globalization on environmental degradation is relatively less discussed in the environmental literature. However, studies such as Shahzad et al. (2022) probed into the impact of financial globalization on the ecological footprint using the period between 1996 Q1 and 2019 Q4. They established that financial globalization helps to increase the ecological footprint. However, the research of Kihombo et al. (2021) opposes this outcome. They established a negative relationship between financial globalization and ecological footprint in WAME (West Asian and the Middle East) economies spanning between 1990 and 2017. Ulucak et al. (2020) studied the interaction between ecological footprint and financial globalization using the ARDL and DOLS for emerging economies using the dataset from 1974 to 2016. They found that financial globalization reduces the ecological footprint. The study of Chen et al. (2021) on the association between financial globalization and $CO_2$ emissions for the period between 1970 and 2018 used the NARDL in which India is the country of focus. The empirical outcome indicates that the increase in financial globalization will reduce $CO_2$ emissions and the decrease in the level of globalization will increase $CO_2$ emissions in India.

The research mentioned above provides an essential foundation for the growing degree of environmental challenges in emerging economies such as Brazil and developing economies. Although no studies have been conducted on the influence of financial globalization, urbanization, economic growth, and renewable and nonrenewable energy usage on load capacity factor. As a result, our study takes these variables into account as crucial considerations for sustainable development and the environment.

# MATERIAL AND METHODOLOGY

## Empirical Framework

Grossman and Krueger (1991) postulated the environmental Kuznets curve (EKC) hypothesis, which stipulated that the association between economic expansion and the environment has an inverted U-formed association, which is segmented into 3 phases (scale, composition, and technological). The scale impact shows that increased production pollutes the environment. The composition impact represents an economic sectorial shift. Environmental degradation appears to be growing during the transition from agricultural to industry, whereas the level of pollution significantly reduces following the transition from industry to services. Finally, the technological effect demonstrates that eco-friendly technologies and industrial practices could increase environmental quality.

Also, energy consumption is among the primary drivers of environmental degradation even though it is the heartbeat of any economy (Dogan et al., 2020; Shahzad et al., 2020; Fatima et al., 2021). Numerous nations across the globe utilize fossil fuels like coal, natural gas, and oil to promote population explosion, urbanization, and industrialization resulting in increased degradation of the environment. Given the recent increased levels of emissions, mitigation techniques must be developed to regulate the concentration of greenhouse gas. However, there has been no consensus on the best methods to minimize severe damage to the environment. However, renewable energy has become a credible option for fossil fuels in recent years. The reason for this increase in prominence is that there are several types of renewable energy sources that are sustainable, unlike fossil fuels that emit heavily. Renewable energy sources have the prospect to decrease energy prices, improve air quality as well as human health, and generate employment (Kirikkaleli and Adebayo, 2021; Paramati et al., 2022). Moreover, using indigenous renewable energy resources, for instance, biomass, wind, geothermal, and solar, can help maintain energy security and reduce energy import prices (Adebayo and Kirikkaleli, 2021; He et al., 2021).

Aside from economic expansion, various other variables, like globalization, might impact either through composition, scale, and technique impacts, which may explicitly define these influences. As a result, globalization is an important aspect that can influence the interaction between economic expansion and environmental degradation. Based on the financial globalization perspective, there are several forms in which financial globalization could contribute to environmental degradation. One such form is through scale effect since the level of consumption and economic activities can be stimulated by financial globalization. Also, financial globalization encourages economic activity through cross-border activities, which boosts the industrial activity of the nation and, as a result, increases environmental degradation. Furthermore, the stock market's strong performance suggests an increase in economic progress, which promotes consumer and business confidence, stimulates production and consumption, and contributes to increased environmental deterioration. Financial globalization, on the other hand, has the potential to increase the environment quality via technique and composition impacts by facilitating more ecologically friendly initiatives. Also, an important component influencing the quality of the environment is urbanization, which increases the demand for natural resources. Therefore, uncontrolled urbanization is potentially damaging to the environment, whereas when urbanization is sustainable, it has the potential to alleviate the negative environmental effects of urbanization. As a result, it is considered that when urbanization is not properly handled, it might lead to ecological deterioration. Based on the above knowledge, we formulated the following economic function as follows:

$$LCAP_t = f\,(GDP_t,\ NREN_t,\ REN_t,\ FGLO_t,\ URB_t) \quad [1]$$

The empirical model is presented as follows:

$$LCAP_t = GDP_t + NREN_t + REN_t + FGLO_t + URB_t + \epsilon_t \quad [2]$$

where: LCAP denotes load capacity factor, GDP denotes economic growth, NREN denotes non-renewable energy, REN denotes renewable energy, FGLO denotes financial globalization, URB denotes urbanization, $\epsilon$ denotes error term, and t denotes the sample period (1970–2017).

## Data Information

This research examined the impact of financial globalization, urbanization, economic growth, and renewable and nonrenewable energy usage on load capacity factor for the period stretching between 1970 and 2017. The beginning period of 1970 was chosen owing to the availability of data for financial globalization, while the ending year of 2017 was chosen owing to the absence of load capacity factor data ending in the year 2017. The information on non-renewable and renewable energy was gotten from the BP database, economic and growth urbanization were gotten from the World Bank database. Load capacity factor was gotten from the Global Footprint Network. Last, financial globalization was collected from the KOF index. The observed series were transmuted into their natural logarithms to ensure the reduction in the chance of distortions during estimation. The descriptions of the observed series are depicted in **Table 1**. The analysis flow is presented in **Figure 2**.

## Methodology

### Unit Root Test

Owing to its inability to include the structural shift into the regression procedure, the conventional unit roots test offers inconsistent outcomes. We solve this issue by applying the ZA unit root, which can detect at least one structural shift during analysis. The ZA unit root is defined as:

$$\text{Model A: } \Delta y = \sigma + \hat{u} y_{t-1} + \beta t + \gamma DU_t + \sum_{j=i}^{t} d_j \Delta y_{t-j} + \varepsilon_t \quad [3]$$

$$\text{Model B: } \Delta y = \sigma + \hat{u} y_{t-1} + \beta t + \Theta DT_t + \sum_{j=i}^{t} d_j \Delta y_{t-j} + \varepsilon_t \quad [4]$$

$$\text{Model C: } \Delta y = \sigma + \hat{u} y_{t-1} + \beta t + \Theta DT_t \gamma DU_t + \sum_{j=i}^{t} d_j \Delta y_{t-j} + \varepsilon_t \quad [5]$$

where the shift in mean of the dummy parameter that happens at a probable break-date is denoted by $DU_t$; the shift in trend of the variable is denoted by DTt. Model A indicates the intercept; Model B is the trend, while Model C indicates intercept and trend (both).

**TABLE 1** | Description of the variable.

| Indicators | Description | |
|---|---|---|
| LCAP | Load capacity factor | Global Footprint Network |
| NREN | Non-renewable energy consumption | BP database |
| REN | Renewable energy consumption | |
| GDP | GDP per capita (constant 2015 US$) | World Bank database indicators |
| URB | Urbanization | |
| FGLO | Globalization index based on financial | KOF Globalization Index |

Formally,

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

## ARDL Bounds Testing Approach

The ARDL bound test initiated by Pesaran et al. (2001) was utilized to ascertain the long-run linkage after exploring the order of integration among the variables used. There are several cointegration techniques, but this study deployed the ARDL bound test because it is more advantageous compared to the other cointegration techniques due to the following reasons;: (1) the bound test is flexible and allows variable integrated at the order I (0) and 1 (1) to be utilized in the model; (2) generates long-run unbiased estimation; (3) compared to the conventional cointegration tests, small sample size can be estimated using ARDL bound test, and (4) endogeneity problem is addressed by this method (Kirikkaleli et al., 2021) The F-statistic proposed by Pesaran et al. (2001) was compared with critical bound values to check the cointegration. The null and alternative hypothesis for this test is that there is no cointegration in the long run, and there is cointegration in the long run, respectively. For the alternative hypothesis to be accepted, the F-Stat must be higher than the upper bound critical value at 1, 5, or 10%, respectively.

The ARDL model in this paper is depicted in **Equation (7)**.

$$\begin{aligned}\Delta LCAP_t = {} & \theta_0 + \sum_{l=1}^{p}\theta_1\Delta LCAP_{t-1} + \sum_{i=1}^{p}\theta_2\Delta GDP_{t-1} \\ & + \sum_{i=1}^{p}\theta_3 NREN_{t-1} + \sum_{i=1}^{p}\theta_4\Delta REN_{t-1} \\ & + \sum_{i=1}^{p}\theta_5\Delta FGLO_{t-1} + \sum_{i=1}^{p}\theta_6\Delta URB_{t-1} + \sum_{i=1}^{p}\theta_7\Delta DUM_{t-1} \\ & + \pi_1 LCAP_{t-1} + \pi_2 GDP_{t-1} + \pi_3 NREN_{t-1} + \pi_4 REN_{t-1} \\ & + \pi_5 FGLO_{t-1} + \pi_6 URB_{t-1} + \pi_7 DUM_{t-1} + \epsilon_t \end{aligned} \quad [7]$$

In **Equation (6)**, the variable's coefficients of the short-run dynamic are represented by $\theta_i\,(i = 1\ldots4)$, the long-run connection among variables is shown by $\pi_i\ (i = 1\ldots5)$, lag lengths are illustrated by t. Integrating the ECM into the ARDL short-term parameter, which transforms **Equations (7)** and **(8)**:

$$\begin{aligned}\Delta LCAP_t = {} & \theta_0 + \sum_{l=1}^{p}\theta_1\Delta LCAP_{t-1} + \sum_{i=1}^{p}\theta_2\Delta GDP_{t-1} + \sum_{i=1}^{p}\theta_3 NREN_{t-1} \\ & + \sum_{i=1}^{p}\theta_4\Delta REN_{t-1} + \sum_{i=1}^{p}\theta_5\Delta FGLO_{t-1} + \sum_{i=1}^{p}\theta_6\Delta URB_{t-1} \\ & + \sum_{i=1}^{p}\theta_7\Delta DUM_{t-1} + \pi_1 LCAP_{t-1} + \pi_2 GDP_{t-1} \\ & + \pi_3 NREN_{t-1} + \pi_4 REN_{t-1} + \pi_5 FGLO_{t-1} \\ & + \pi_6 URB_{t-1} + \pi_7 DUM_{t-1} + \pi_8 \alpha ECT_{-1} + \epsilon_t \end{aligned} \quad [8]$$

where the speed of adjustment of short run to attain equilibrium in the long-term is represented by $\varphi$ and the error correction term is indicated by $ECT_t$. The predictable symbol of this coefficient, as anticipated, is negative and significant. After identifying the cointegration association in **Equation (6)** the ARDL method was utilized to analyze the dynamic interaction between $CO_2$ emissions and its determinants.

## Frequency Domain Causality

Finally, this study also examines the causality association between load capacity and its determinants in the short, medium, and long term. This approach offers vital information on causal association at distinct frequency (period) compared to the conventional causality approach. Thus, it is suitable for analyzing time-dependent disturbances in a specific frequency domain. The method is based on a reconstructed Vector Autoregressive (VAR) between x and y, which is expressed as:

$$x_t = \theta_1 x_{t-1} + \ldots. + \theta_1 x_{t-1} + \beta_1 y_{t-1} + \ldots + \beta_l y_{t-1} + \varepsilon_t \quad [9]$$

In the selection of lag $l$, the Akaike information criterion (AIC) is used. Focused on Geweke (1982)'s null hypothesis $(M)$, which is described as $M_{y\to x}(\omega) = 0$, whereby the frequency $\omega\varepsilon(0,\pi)$, and modified null hypothesis ($H_o$) is expressed as follows:

$$H_0:\ R(\omega)\beta = 0 \quad [10]$$

The vector connected to y coefficients is symbolized by $\beta$

$$R(\omega) = \frac{\cos(\omega)\cos(2\omega)\ldots.\cos(l\omega)}{\sin(\omega)\sin(2\omega)\ldots.\sin(l\omega)} \quad [11]$$

Frequency $\omega$ is linked to period t as $t = \frac{2\pi}{\omega}$.

# EMPIRICAL FINDINGS

**Table 2** displays the observed series' descriptive properties, which is the pre-estimation. Among the variable used, urbanization has the highest average value while load capacity factor has the lowest average value. However, economic growth is the second average value in the considered variable. In the context of the skewness and kurtosis of the observed series, financial globalization, urbanization, economic growth, and renewable and non-renewable energy usage are negatively skewed while the load capacity factor is positively skewed. Also, a low tailed peakedness of less than 3 was evident in all observed series, suggesting that there are platykurtic in nature except for economic growth and renewable energy. Thus, this indicates that all observed series are

**TABLE 2** | Descriptive statistics.

| | LCAP | URB | NREN | FGLO | REN | GDP |
|---|---|---|---|---|---|---|
| Mean | 0.617 | 8.038 | 3.815 | 1.552 | 3.601 | 3.8157 |
| Median | 0.599 | 8.072 | 3.796 | 1.542 | 3.672 | 3.812 |
| Maximum | 0.864 | 8.249 | 4.019 | 1.740 | 3.836 | 3.966 |
| Minimum | 0.468 | 7.707 | 3.537 | 1.321 | 3.071 | 3.560 |
| Std. Dev | 0.105 | 0.165 | 0.109 | 0.133 | 0.208 | 0.091 |
| Skewness | 0.611 | −0.478 | −0.212 | −0.138 | −1.027 | −0.495 |
| Kurtosis | 2.589 | 1.966 | 2.976 | 1.716 | 3.119 | 3.521 |
| Jarque-Bera | 3.329 | 3.970 | 0.360 | 3.446 | 8.458 | 2.506 |
| Probability | 0.189 | 0.137 | 0.835 | 0.178 | 0.015 | 0.286 |

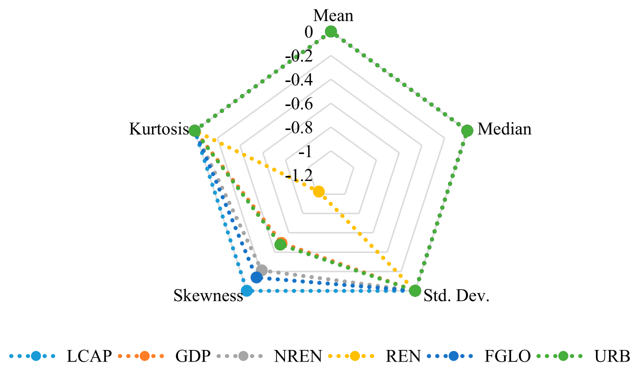


**FIGURE 3** | RADAR chart.

**TABLE 3** | Structural break unit-roots outcome.

| | I (0) | I (1) |
|---|---|---|
| LCAP | −3.257 (2001) | −6.802[a] (1980) |
| GDP | −4.523 (2010) | −6.217[a] (1984) |
| NREN | −3.559 (1983) | −6.350[a] (1989) |
| REN | −3.098 (1999) | −7.613[a] (2003) |
| FGLO | −3.837 (2007) | −7.911[a] (1992) |
| URB | −2.332 (1981) | −5.862[a] (2002) |

[a]*Portray significance level of 0.01; structural breaks are in parentheses.*

normally distributed and supported by the observed series' Jarque-Bera test and its probability value. Moreover, as shown in **Figure 3**, the RADAR chart offers a graphical representation of the observed series' descriptive statistics.

Before computing the effect of urbanization, non-renewable energy, financial globalization, renewable energy, and economic growth on load capacity, the stationary properties of the observed series need to be undertaken to establish the integration order. This current research employed the Zivot Andrew unit root test that helps to detect the stationarity nature of the series in the presence of a structural break, unlike the conventional unit root test. **Table 3** presents the outcome of the Zivot Andrew test. Thus, the outcomes from the estimates are reliable and accurate. All series are stationary at first difference with the structural break in 1980, 2002, 1989, 1992, 2003, and 1984 for load capacity, urbanization, non-renewable energy, financial globalization,

**TABLE 4** | ARDL approach to cointegration.

| F-statistic | 4.473[a] | | | | | |
|---|---|---|---|---|---|---|
| T-statistic | −6.021[a] | | | | | |
| | Kripfganz and Schneider critical values | | | | | |
| | 1% | | 5% | | 10% | |
| | LB | HB | LB | HB | LB | HB |
| F-statistic | 3.15 | 4.43 | 2.45 | 3.61 | 2.12 | 3.23 |
| T-statistic | −3.43 | −4.99 | −2.86 | −4.38 | −2.57 | −4.04 |

[a]*Portray significance level of 0.01.*

renewable energy, and economic growth, respectively. For a more robust cointegration and long-run results analysis, the break of 1980 in load capacity is integrated into the model. This break coincides with the period of increase in risk in the economic and political environment. Such issues play a crucial role in affecting major macroeconomic parameters, which resulted in disruption in load capacity factor.

Following the validation of the integration order, the next phase of the current research is to evaluate the cointegrating interaction utilizing the bounds testing procedure. However, the critical values and approximate *p*-values, which is the innovation of Kripfganz and Schneider (2018), are used in this investigation, which is presented in **Table 4**.

Based on the report of **Table 4**, at 1% significance level, the computed value of the F-statistic of 4.473 exceeds the critical value of 4.43. Likewise, at the 1% level of significance, the absolute value of the t-statistic is −6.021, which exceeds −4.99, which is the absolute critical value. Since the *p*-values obtained with the analysis are less than 0.01, this shows that the null hypothesis of non-cointegration is rejected. Thus, the F- and t-statistics, as well as their probability values, corroborate the presence of cointegration among the observed series at the 1% level.

Given that the cointegration connection is evident, the ARDL approach is utilized to evaluate the impact of these regressors (GDP, NREN, REN, FGLO, and URB) on load capacity. The results of the ARDL technique are shown in **Table 5**. GDP reduces load capacity factor in the long run. Also, renewable and non-renewable energy decrease load capacity factor in the long term. However, urbanization has no significant association with load capacity factor. However, financial globalization increases the quality of the environment. Moreover, the error correction term is negative and significant with its value as 0.379 (37.9%), suggesting that imbalances in the observed parameters can be eliminated within a short period, thereby the series would eventually converge to the long-run equilibrium.

For more detailed analysis, economic growth exerts a negative association with load capacity factor in the long run. The increase in GDP by 1% will reduce load capacity by 0.462% in the long term. Thus, economic expansion impedes the quality of the environment in the long run. This outcome aligns with the outcome of Akinsola et al. (2021), Bildirici (2018), Ben Jebli and Ben Youssef (2019), who conclude that economic growth contributes to environmental degradation even though they employed different proxies for environmental degradation as dependent variable and time coverage of analysis. The finding

**TABLE 5 |** ARDL estimators outcome.

| Variable | Coefficients | T-statistics |
|---|---|---|
| GDP | −0.462* | −2.606 |
| NREN | −0.191*** | −1.988 |
| REN | −0.177*** | −3.467 |
| FGLO | 0.047*** | 1.909 |
| URB | 0.042 | 0.580 |
| DUM | 0.025*** | 1.903 |
| ECT (-1) | −0.379* | −6.021 |
| **Diagnostic Check** | | |
| $\chi^2$ Normality | 0.390 (0.823) | |
| $\chi^2$ LM | 0.047 (0.829) | |
| $\chi^2$ Heteroscedasticity | 1.213 (0.318) | |
| $\chi^2$ Ramsey | 0.270 (0.789) | |

*** and * portray significance levels of 0.1 and 0.01;* p-value *in parentheses.*

indicates that Brazil is presently at the scale phase, indicating that Brazil is running a pro-growth agenda. The cost of economic expansion experienced in Brazil comes in the form of environmental issues like pollution on the land, sea, and air. As an emerging economy, Brazil consumes a vast amount of natural resources and makes use of carbon-intensive energy resources to boost its economy. Brazil's explosive growth is centered on resource-intensive manufacturing, and exports have essentially reached their limitations, resulting in environmental issues. Thus, Brazil's economic expansion, particularly during the 2000s, has resulted in intensifying the deterioration of the environment. This demonstrates that increasing per capita income does not always result in a sustainable environment, and as a result, the authorities in Brazil must implement energy-related environmental policies.

Non-renewable energy exhibits a negative and significant interrelationship with load capacity factor in the long term. The increase in non-renewable energy by 1% will reduce load capacity factor by 0.191% in the long run. This outcome corresponds with the findings of Adebayo et al. (2021) for Japan, Bekun et al. (2021) for South Africa, and Usman et al. (2021) for the 15 highest emitting countries, who found that non-renewable energy deteriorates the environment. Fossil fuel constitutes about 63.99% of the energy basket of Brazil as of 2017 (Our World in Data, 2021), which is responsible for the industrial and production activities of the economy. Brazil's strong reliance on fossil fuel generates waste and increases pressure on the environment by polluting the atmosphere, decreasing soil quality, and poisoning aquatic bodies.

Renewable energy exerts a negative and significant interaction with load capacity factor in the long term. The surge in renewable energy by 1% will decrease the level of load capacity factor by 0.177% in the long term. This outcome does not correspond with the findings of Alola et al. (2021) and Amarante et al. (2021), who reported that renewable energy can help to achieve a sustainable environment in China and Brazil. Also, Pata (2021) reported a positive association between load capacity factor and renewable energy consumption in the United States. The possible reason for the adverse influence of renewable energy on the environment is that hydropower constitutes a large proportion of the renewable energy mix of Brazil. According to Von Sperling (2012), the construction of hydropower plants poses social and environmental issues, such as minimized recreational benefits of river, obstructed fish migration, changes in water quality, low flow reaches, emission of GHGs, siltation, and damaged wildlife habitat.

Having uncovered the effect of renewable energy, this current research unfolded a significant and positive association between financial globalization and load capacity factor, suggesting that a 1% surge in financial globalization will boost the level of load capacity factor by 0.047%. Hence, financial globalization plays a crucial role in achieving a sustainable environment in Brazil. This conclusion also receives backing from the studies of Kihombo et al. (2021) and Ahmad et al. (2021) who uncovered an identical association in WAME and G7 economies, respectively. This outcome is reasonable since foreign investment might provide efficient technology, which can enhance productivity in a country with limited resources. Besides, the availability of financial resources can help to boost green energy initiatives.

Moreover, there is a negative and insignificant association between urbanization and load capacity factor in the long term. Thus, urbanization does not influence the environment in Brazil. The possible reason could be that the level of urbanization is not strong enough to affect the quality of the environment. This

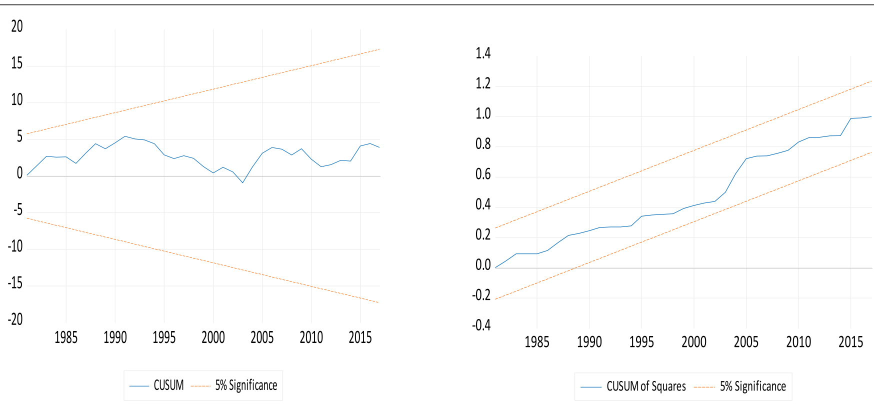


**FIGURE 4 |** Stability test.

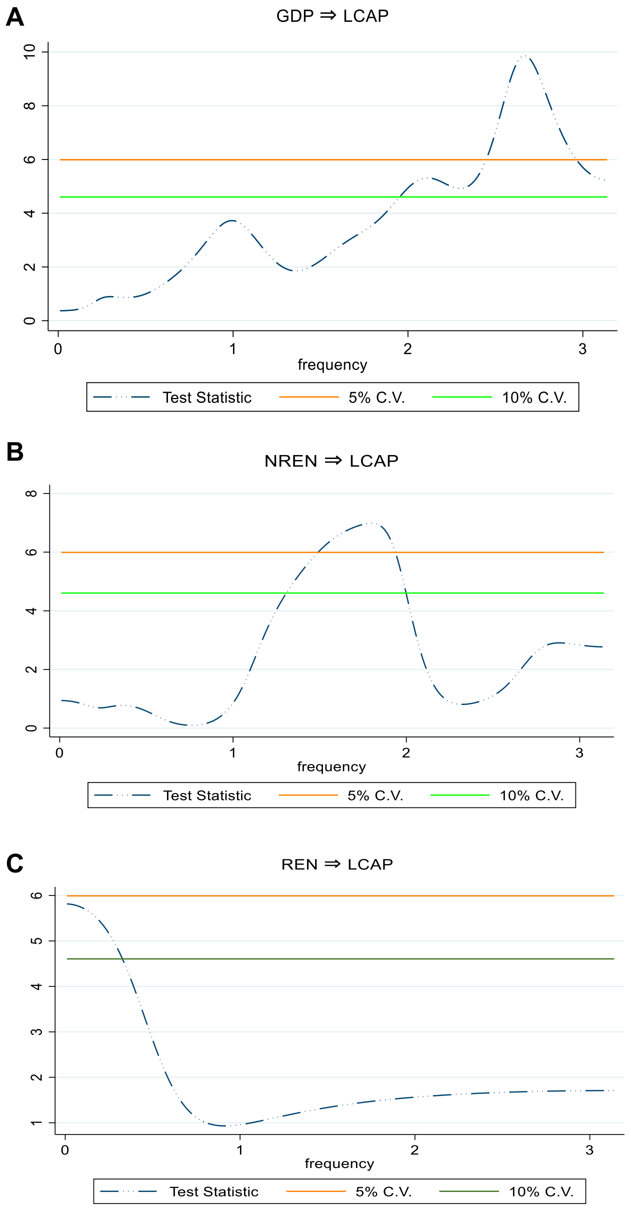


**FIGURE 5 | (A)** Spectral BC causality from GDP to LCAP. **(B)** Spectral BC causality from NREN to LCAP. **(C)** Spectral BC causality from REN to LCAP. **(D)** Spectral BC causality from FGLO to LCAP. **(E)** Spectral BC causality from URB to LCAP.

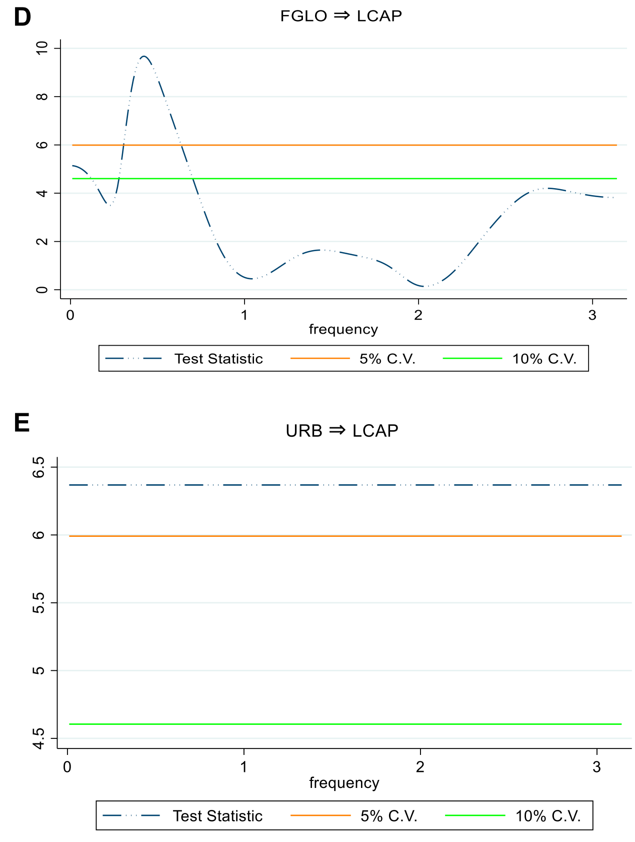


**FIGURE 5 |** *(Continued)*.

outcome aligns with the outcome of Nathaniel and Khan (2020), who found no interaction between ecological footprint and urbanization for ASEAN economies. They failed to comply with the study of Rafique et al. (2021), who found a negative interaction between ecological footprint and urbanization for 10 selected countries. Also, the study of Solarin et al. (2021) found a negative interaction between ecological footprint and urbanization in G-7 countries.

We performed some post-estimation tests to determine the goodness of fit of the ARDL model, as mentioned in the preceding portion of the study. These diagnostic tests are presented in **Table 5**, and they show that the residual of this model does not suffer heteroscedasticity, misspecification, or serial correlation issues. This model's residuals are also normally distributed. Also, the CUSUM and CUSUMSQ tests show that the models are stable at the 5% level of significance, as shown in **Figure 4**. Based on the estimates obtained from the post-estimation test, we conclude that the ARDL model is robust and reliable for policy direction.

Since the long coefficients of the regressors with load capacity factor are uncovered, the next phase of our empirical analysis is to detect the causal association between load capacity factor and its regressors (REN, NREN, FGLO, URB, and GDP). This research employed the spectral BC causality technique for this purpose. As stated earlier, the advantage of this technique is that it is capable of the causal interaction at different frequencies, which is the limitation of the conventional Granger causality techniques. The results of the causal interconnection from the regressors to load capacity factor are showcased in **Figures 5A–E**. The lime and orange solid lines symbolize the 0.1 and 0.05 level of significance, whereas the T-statistics computed by this technique are denoted as the long-dash-dotted line. The result of the causal interaction running from GDP to load capacity factor is evident in the long term as reported by **Figure 5A**. Thus, economic growth predicts load capacity factor only in the long term. Also, the outcome of the causal connection from non-renewable energy to load capacity factor is reported in **Figure 5B** and is detected in the middle and long term. Therefore, non-renewable energy is a predictive factor of load capacity factor in the middle and long frequency in Brazil. For the causal association between renewable energy and load capacity factor, **Figure 5C** indicates that causality can be established only in the short term. As a result, renewable energy predicts load capacity factor in the short term in Brazil. The finding of the unidirectional causal connection from financial globalization to load capacity factor is detected in the short term as seen in **Figure 5D**. Thus, financial globalization predicts load capacity factor only in the short term in Brazil. **Figure 5E** indicates that the null hypothesis of non-causality from urbanization to load capacity factor was not rejected at any level of significance. This outcome provides backing for the finding of the ARDL techniques.

Based on these findings, it is observable that non-renewable energy, financial globalization, renewable energy, and economic growth are predictive agents of load capacity in Brazil. Hence, any initiatives aimed at enhancing non-renewable energy, financial globalization, renewable energy, and economic growth will have a significant impact on load capacity for the case of Brazil.

## CONCLUSION AND POLICY DIRECTIONS

### Conclusion

Brazil is an emerging economy that is placed on severe environmental concerns due to its rapid growth in the economy. Much research has evaluated environmental deterioration in both developed and developing nations using commonly utilized indicators such as carbon emissions, ecological footprint, and greenhouse gas emissions. To mitigate environmental challenges and fulfill the Sustainable Development Goals, a broader and holistic ecological assessment is required. As a result, this research utilizes the load capacity factor, which is a distinct proxy of environmental deterioration that offers a detailed environmental evaluation measurement by comparing biocapacity and ecological footprint simultaneously. Moreover, the load capacity factor provides the combined attributes of the demand and supply-side of environmental quality.

Using Brazil as the focus of the investigation, this research examined the effect of financial globalization, urbanization, economic growth, and renewable and nonrenewable energy usage on load capacity for the period stretching between 1970 and 2017. To discover these connections, a plethora of econometric techniques were utilized. The present research employed the ZA unit roots test to detect the order of integration of the observed series, which are integrated at I (1). The bounds testing procedure for cointegration in combination with the critical approximation $p$-values of Kripfganz and Schneider (2018) disclosed a cointegrating association between load capacity and its regressors. The outcome of the ARDL method uncovered that economic growth, and non-renewable and renewable energy reduce the load capacity factor, whereas urbanization has no impact on the load capacity factor in Brazil. However, financial globalization has a positive impact on the load capacity factor in Brazil.

The outcome of the spectral BC causality approach disclosed the following: (1) economic growth predicts load capacity factor only in the long term; (2) non-renewable energy is a predictive factor of load capacity factor in the middle and long frequency; and (3) renewable energy and financial globalization predict load capacity factor in the short term.

### Policy Directions

First, disregarding environmental issues for the sake of economic growth in Brazil will result in considerably greater catastrophic issues in the coming decade. Considering the detrimental influence of GDP on environmental quality in both the short and long term, the Brazilian policymakers should comply with environmental standards by enacting policies in the aspects of energy, education, and natural resource management. Also, Brazilian policymakers should exercise caution when developing economic development strategies that endanger ecological sustainability. Creating a circular framework for the industrial sector will strongly encourage the recycling of industrial and residential waste.

Second, to mitigate the effect of energy consumption (non-renewable and renewable energy) on environmental degradation, the country needs to upsurge the share of other renewable energy sources such as solar and wind energy in the energy basket of the country. Also, the investment, as well as the research and development expenditure should be channeled to other renewable energy that entails a small proportion of the country's energy mix. Furthermore, intentionally promoting the development of low-carbon technology, which seems to be significant considerations in the country's strategy toward achieving decarbonization, strengthens technological innovations for cleaner energy.

Third, the outcome indicates that financial globalization is sustainable in Brazil, the policymaker should take advantage of the opportunity by developing policies that encourage the openness of the economy to foreign investors. The inflows of foreign capital continue to increase will help to drive growth in the country's domestic financial markets. Strong and established financial markets are increasingly prone to offer finances for the investment and development of green technologies. Brazil also should create policies to ensure that its economic expansion is uninterrupted since a high degree of development will help improve its load capacity factor.

Last, this finding presents new investigation possibilities. For future investigation, the impact of energy consumption, urbanization, and financial globalization on the load capacity factor may be examined using various methodologies. Furthermore, future studies could be conducted for specific nations or groups of nations.

## DATA AVAILABILITY STATEMENT

Publicly available datasets were analyzed in this study. This data can be found here: https://data.footprintnetwork.org/?_ga=2.225986457.2064820888.1631940939-2048938146.1624442110#/countryTrends?type=BCpc,EFCpc&cn=21 https://data.worldbank.org/.

## AUTHOR CONTRIBUTIONS

XD: Writing the original manuscript, writing– review and editing. SS: Reviewed the paper and made corrections. AA: Conceptualization, data collection, formal analysis, and methodology. GA: Writing– review and editing, validation. MA: Writing original manuscript and data collection. DO: Editing and validation. DK: Writing–review and editing, administration. OO: Writing original manuscript and data collection. All authors approved the final manuscript.

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