Determinants of load capacity factor in an emerging economy: The role of green energy consumption and technological innovation

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Brazil's ability to provide safe and dependable resources that can assist the nation achieve its goal of becoming carbon neutral by 2060 will have a significant impact on the nation's sustainable development. Therefore, this study performs ARDL and frequency domain causality tests to evaluate the effect of disintegrated energy, technological innovation and economic growth on load capacity factor in South Africa between 1990 and 2018. The ARDL bounds test affirms a long-run interrelationship between the selected indicators in South Africa. The long-run elasticities show that economic expansion and nonrenewable energy deteriorate ecological quality, while green energy and technological innovation significantly boost ecological quality. The results of the frequency causality show that in the long-term, renewable energy, economic growth, technological innovation and nonrenewable energy Granger cause load capacity factor suggesting that the regressors can forecast the environmental quality in South Africa. Overall, these results demonstrate the significance of renewable energy in the fight against ecological deterioration. According to the aforementioned findings, South Africa's environmental damage may be greatly reduced by renewable energy.

Introduction

Governments' adoption of unsound economic ideas may be to blame for the constantly worsening climate; these strategies may endanger both the environment and individuals (Balsalobre-Lorente et al., 2022; Jiang et al., 2022). The policymakers' primary focus is on achieving high rates of economic growth, without giving adequate regard to ecological quality. As a result, ensuring sustainable economic growth must be a top priority for governments in both developing and developed nations. Furthermore, one of the most crucial efforts for nations to accomplish sustainable development is to boost economic expansion concurrently with objectives surrounding better ecological quality and preventing environmental harm Abdulkareem et al. (2022).

Energy is necessary for economic growth, but it may also be the primary factor responsible for ecological deterioration. Governments and scholars alike are taking the energy-environment nexus into serious account (Jahanger et al., 2022a; Jahanger et al., 2022b; Usman and Balsalobre-Lorente, 2022). Several experts contend that non-renewable energy, not renewable energy, is to blame for the adverse consequences on the environment. Consequently, switching to a higher percentage of renewable energy instead of non-renewable energy offers a range of potential benefits, such as reducing emissions that contribute to global warming, reducing reliance on non-renewable energy and diversifying energy sources (Doğan et al., 2022; Samour et al., 2022; Sinha et al., 2022; Gyamfi et al. (2022)).

The desire to achieve ecological sustainability has led to the establishment of a number of projects and elements that are seen to be successful in generating carbonless growth or growth, that is, beneficial to the ecosystem. Among the many possible environmental factors, technological advancements stand out for at least three reasons (Zhang Q. et al., 2022; Panait et al., 2022). First, most growth theories emphasize the importance of technological advancements in breaking through growth constraints. Examples include the technical advancements made by New Growth and Neoclassical theorists, as well as the technological interference seen in the Malthusian theory of population growth (Acheampong et al., 2022). The demanding problems provided by growth to the ecosystem are extrapolated from the intervening roles of technology in addressing concerns surrounding growth theories. To that aim, economic expansion is made possible with minimal to no environmental impact thanks to technology advancements. Second, with solid technology advancement, environmental pollution adaption and mitigation measures will become more effective and efficient. Therefore, technology is the most important last resort for combating the growing negative impacts of environmental deterioration (Omri and Bel Hadj, 2020). Third, the interaction of technology is crucial to the efficacy of indicators like renewable energy, industries driven
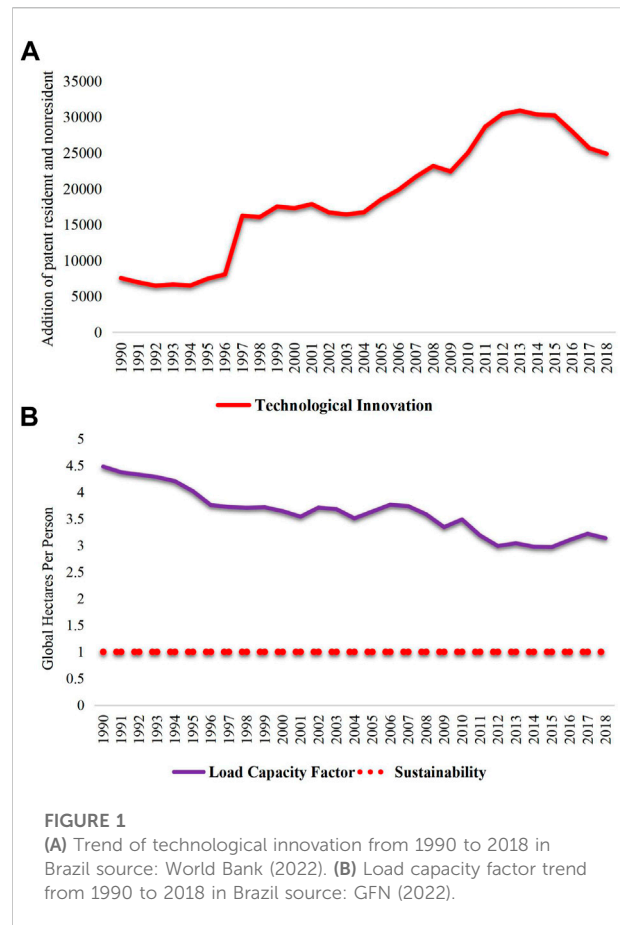

FIGURE 1
(A) Trend of technological innovation from 1990 to 2018 in Brazil source: World Bank (2022). (B) Load capacity factor trend from 1990 to 2018 in Brazil source: GFN (2022).

by services, and environmental policy, among others. In recent decades, investment in technological innovation is high as shown by Figure 1A.

Recent studies have examined the factors that influence Brazil's ecological footprint. For instance Su et al. (2021) in their study on the drivers of environmental degradation reported that REC boost ecological sustainability while NREC and economic progress diminishes ecological sustainability Likewise, the study of Adeshola et al. (2022) in Brazil reported that the main architect of environmental sustainability in Brazil is renewable energy while economic growth dampens ecological sustainability. Nonetheless, these investigations ignore the supply side of the ecosystem and only pay attention to the ecological footprint (EF). It is important to take into account the available ecological resources in order to make informed assessments about the enhancement of the environment's quality. In order to improve environmental assessments, Siche et al. (2010) suggested the load capacity factor (LF). The LF demonstrates a region's or a nation's capacity to sustain its population in line with its existing standard of living. The LF is determined by dividing biocapacity with EF. If the load capacity is less than one, the system is not sustainable under the current ecological

conditions. If it is more than one, the system is sustainable (Pata and Balsalobre-Lorente, 2022). The sustainability limit is equivalent to 1 at this time. Figure 1B presents the ecological condition of Brazil between the period of research.

This research adds to prior studies by evaluating the effect of disintegrated energy on LF in the case of Brazil which is branded by its wealth in the energy sector. This paper applies the novel dynamic ARDL which is a superior approach to the convention ARDL. Second, the paper employs the frequency causality which has the capability to identify causality at all frequencies. Lastly, we employed a broader measure of environmental quality which considers both the demand as well as supply sides ecological issues.

The remainder of this discourse is organized as follows. After this introduction (Section 1), a critical analysis of earlier studies on the study variables is depicted in Section 2. The methods and data are presented in Section 3. Section 4 presents the empirical findings. The key findings and broader policy ramifications are then presented in Section 5.

Literature review

Technological innovation and environment

Both policymakers and academicians are becoming conscious of the relevance of TEC towards reducing environmental degradation as a result of the consistent advancement in innovation level (Agyekum et al., 2022a; Agyekum et al., 2022b; Du et al., 2022; Haldar and Sethi, 2022; Kirikkaleli et al., 2022). In recent years, there has been a lot of study on TEC. As a result, several researchers have attempted to investigate the effect of TEC on environment. Among these studies, there are various notable indices for measuring the levels of TEC, such as efficiency, R&D, and patent development. However, studies such as Destek and Manga (2021) concluded that TEC contributes to mitigating the level of ecological footprint (EF) in big emerging markets economies. Meanwhile, they also investigate the effect of TEC on CO_2 emissions and found that TEC raises CO_2 emissions in these set of nations.

Similar result of the interaction between TEC and CO_2 emissions, the work of Adebayo and Kirikkaleli (2021) explored the influence of TEC on CO_2 emissions in Japan. The findings unveiled that TEC spurs emissions level in Japan. Adeshola et al. (2022) in the case of Portugal, revealed that TEC positively affect CO_2 emissions. Furthermore, Su et al. (2021) evaluated TEC-CO_2 emissions association in Brazil utilizing an annual dataset of 1990–2018. Using the ADRL method for the empirical analysis to probe this association and discovered that TEC is pertinent for the surge in CO_2 emissions.

Moreover, Fareed et al. (2022) in their research of TEC-CO_2 emissions association in NICs for the period between 1995 and 2018, uncovered that the surge in CO_2 emissions and EF can be attributed to the increase in TEC. Meanwhile, detected that TEC negatively affect CO_2 emissions in South Korea. Such adverse

connection between TEC and CO_2 emissions was observed in the study of Akadiri S. S. et al. (2022) in NICS. Moreover, Xie et al. (2022) inspected the factors of CO_2 emissions in China using the ARDL method. The researchers' utilized a dataset between 1985 and 2019, they reported that TEC and CO_2 emissions interaction is negatively related. Focusing on Turkey, Xu L. et al. (2022) inspected the role of TEC in reducing emissions. The research unveiled that the mitigation of emissions in Turkey is attributable to the surge in the TEC. Likewise, Sharif et al. (2022a) inspected the TEC-emissions nexus in G7 economies applying the data between 1995 and 2019. The association was identified using the CS-ARDL method and revealed that TEC plays an important role in abating emissions.

Using WAME's dataset, Kihombo et al. (2021) discovered evidence of the adverse effect of TEC on EF. Zhang W. et al. (2022) recently established that the influence of TEC on EF in BRICS is negative. They employed the dataset spanning between 1990 and 2018. Moreover, Destek and Manga (2021) concluded that TEC contributes to mitigating the level of ecological footprint (EF) in big emerging markets economies. Meanwhile, they also investigate the effect of TEC on CO_2 emissions and found that TEC raises CO_2 emissions in these set of nations. Rout et al. (2022) assessed TEC-EF association in BRICS utilizing a panel dataset of 1990–2018. Using the PM-ADRL method for the empirical analysis to uncover the association and discovered that the association between TEC and EF is negative. Furthermore, Gupta et al. (2022)'s work in the context of Bangladesh, discovered that TEC reduces EF. Xu Y. et al. (2022) in their work of TEC-EF association in China for the period between 1990 and 20187, disclosed that the decrease in EF can be attributed to the increase in TEC. Similar finding of the interaction between TEC and EF, the work of Suki et al. (2022) inspected the influence of TEC on EF in Malaysia. The findings unveiled that TEC reduces EF level in the country.

The work of Yasmeen et al. (2021) explored the influence of TEC on EF in BRI. The findings unveiled that TEC reduces EF. Moreover, Chu (2022), in the case of OECD nations, revealed that TEC negatively affect EF. Furthermore, Sherif et al. (2022b) considered the TEC-EF nexus in Next-11 nations utilizing the panel dataset between 1992 and 2015. Using the FMOLS and DOLS method for the empirical analysis to evaluate this association and discovered that TEC mitigates EF. Conversely, Kirikkaleli et al. (2022) evaluated TEC-EF association in BRICS utilizing the panel dataset of 1990–2017 and discovered that TEC is pertinent for the surge in EF.

Economic growth, non-renewable energy and non-renewable energy and environment

Economic growth and environment have been probed by several studies for specific country and group of nations.

However, Energy consumption which can be renewable or non-renewable energy plays a critical role in economic expansion, which could either mar or improve the quality of the environment (Jahanger et al., 2022a; Balsalobre-Lorente et al., 2022; Jahanger et al., 2022b; Jiang et al., 2022; Sinha et al., 2022; Usman and Balsalobre-Lorente, 2022). For instance, Adekoya et al. (2022) in their research of GDP-EF association in Africa, uncovered that the surge in EF can be attributed to the increase in GDP. Meanwhile, their study also confirmed that NREN contributes to the surge in EF while the decrease in EF is caused by REC. Similar outcome can be confirm in the work of Amin et al. (2022) detected that the increase in GDP and NREN spurs EF in G11 nations, while the deceasing impact of REC on EF was reported. Fakher and Inglesi-Lotz (2022) in their work of GDP-EF association in OPEC economies, discovered that the increase in EF can be attributed to the increase in GDP and NREC. Meanwhile, the environmental quality can be improved by the usage of REC in these group of nations. Furthermore, Li et al. (2022) assessed GDP-EF interrelationship in 120 nations utilizing panel dataset between 1995 and 2014. The empirical analysis discovered that the increase in GDP and NREC is important for the surge in EF. Moreover, Zhang L. et al. (2022) inspected the factors of EF in 10 nations. The researchers' utilized a dataset between 1990 and 2018, they reported that NREC and GDP positively influences EF, but the usage of REN impact on EF is negative. Likewise, Khan et al. (2022) inspected the GDP-EF nexus in G7 economies employing the data from 1996–2019, this interrelationship is investigated using the FMOLS method and detected that GDP and NREC have an increasing effect on EF.

Meanwhile, Abid et al. (2022) investigated the effect of GDP, REC and NREC on EF in Saudi Arabia. They probed the interrelationship using the BARDL method and detected that REN negatively affect EF, while the GDP and NREC aid in the surge of EF. Wu et al. (2022) investigation in Nordic nations only probed into the role if REC on the environment, they employed the CS-ARDL method and uncovered that REC improves the quality of the environment. Likewise, Akinshola et al. (2022); Chen et al. (2022); Rafei et al. (2022) inspected the GDP-EF nexus in Brazil. The association was uncovered by the deployment of the ARDL method and discovered that GDP increase EF. Furthermore, their investigation discovered that the effect of REC on EF in Brazil is negative. Such adverse connection between REC and EF was observed in the research of Beton Kalmaz and Awosusi (2022) in Malaysia, but the impact of GDP on EF is positive for Malaysia. This same interrelationship was reported in the study of Awosusi et al. (2022), they reported that REC and GDP have an adverse and positive effect on EF in BRICS nations. Moreover, Kirikkaleli et al. (2021) inspected the role of GDP on EF in Turkey. The research unveiled that the GDP has an increasing of EF in Turkey. Alola et al. (2021)'s work in China, reported that GDP and NREC have an increasing impact on EF, while REN decreases EF. Furthermore, Miao et al.

(2022)'s work in NICs, discovered that GDP increase EF, REC mitigates it.

The analysis of the previous literature reveals several gaps that serve as the inspiration for this work. It is clear that previous research on the Brazil did not highlight the need to employ the load capacity which a more comprehensive proxy of environmental degradation than ecological footprint and carbon emissions. As a result, policies tailored towards sustainability could be ineffective for the case of Brazil. Additionally, little information—none in the context of the Brazil—is available about the effect of economic growth, technological innovation, renewable and non-renewable energy on load capacity factor. Only a few studies have employed the Dynamic-ARDL method to probe into the determinants of load capacity factor for any emerging economies. Consequently, this study makes an effort to fill such gaps in the literature in the context of Brazil by focusing on those gaps in the literature. The association between load capacity factor and the regressors is depicted by Figure 2.

Data, theoretical framework, and model

Description of variables and data sources

This research utilizes yearly data from 1990 to 2018 for Brazil to assess the effect of technological innovation and disintegrated energy on load capacity factor. Other control variable is real growth. The disintegrated energy (renewable and nonrenewable), economic growth and technological innovation constitute the regressors while the dependent variable is load capacity factor. Both energy (renewable and nonrenewable) is measure in exajoules and are obtained from BP database. Technological innovation is gathered from World Bank database and is calculated as addition of patent resident and nonresident. Lastly, economic growth is collected from World Bank database and is measured as GDP constant US$2015. Previous studies (Akadiri J. S. et al., 2022; Du et al., 2022; Miao et al., 2022)used this proxy in their study. Figure 3 presents the flow of the analysis.

Methodology

Figure 1 shows the flowchart for the empirical technique.

1) The first step is the data gathering from different sources. Data for the variables are obtained from world bank database and BP database sources.
2) Step 2 provides descriptive statistics including standard deviation, mean, kurtosis and skewness etc.,
3) In order to ascertain whether a unit root exists, the third stage involves performing the ADF, PP, and ZA unit root tests.

FIGURE 2
Load capacity factor determinants.

FIGURE 3
Flow of empirical analysis.
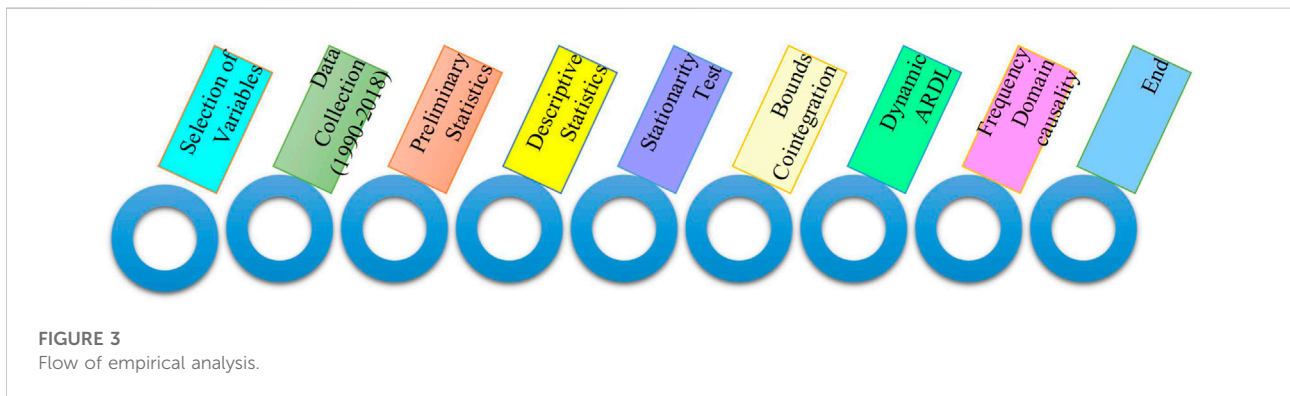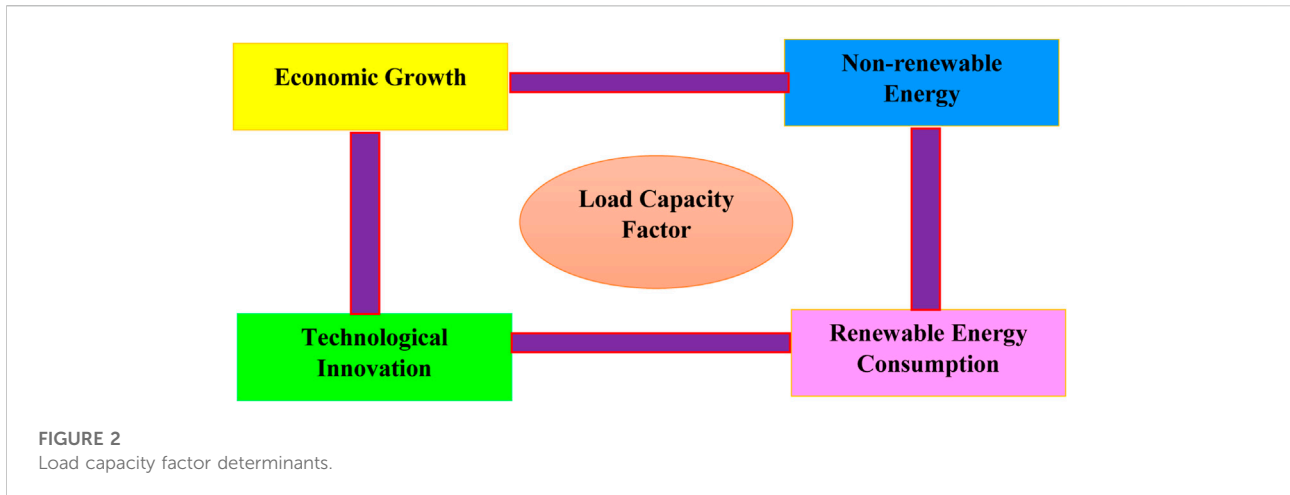
4) The fifth stage looks at cointegration of parameters over the long term using the Bayern and Hanck cointeration test and ARDL bounds test.

5) In the empirical analysis, which is the fifth step, the dynamic ARDL approach is applied to evaluate the impact of the regressors on load capacity factor. The dynamic ARDL approach is used by taking into account the current literature about the impact of technological innovation, economic growth and non-renewable energy use on load capacity factor.

6) In the sixth phase, we evaluate the causal connection between the variables using the frequency domain causality approach.

7) The final stage discusses debate, ramifications, restrictions, and directions in light of the empirical findings.

Regarding the aforementioned methodology, this study employed the empirical model as shown in Eq. 1.

$$LF_t = \beta_0 + \beta_1 GDP_t + \beta_2 REC_t + \beta_3 NREC_t + \beta_4 TEC_t + \varepsilon_t \quad (1)$$

In Eq. 1, LF, GDP, TEC, REC and NREC depicts load capacity factor, economic progress, technological innovation, renewable

and non-renewable energy. $\beta_1 \ldots \ldots \ldots \beta_4$ depicts the coefficients of the regressors. Eq. 1 is altered by taking into account converting the series into the logarithmic form for the econometric investigation.

TABLE 1 Descriptive statistics.

	LF	GDP	TEC	REC	NREC
Mean	3.612715	1.24E + 12	18757.28	45.60995	1439.479
Median	3.640504	8.83E + 11	17849.00	45.43640	1382.411
Maximum	4.477512	2.62E + 12	30884.00	49.86467	2117.411
Minimum	2.966413	4.01E + 11	6474.000	41.43610	829.6470
Std. Dev	0.438213	7.48E + 11	8208.534	2.323443	382.7831
Skewness	0.280330	0.550193	−0.139368	0.016888	0.194672
Kurtosis	2.291980	1.783433	1.873923	2.016540	1.955049
Jarque-Bera	0.985556	3.251486	1.626107	1.170070	1.502575
Probability	0.610927	0.196765	0.443502	0.557086	0.471759

TABLE 2 Unit root outcomes.

	ADF		PP	
	I(0)	*I* (1)	**I(0)**	*I* (1)
LF	−2.130	−4.862*	−2.249	−4.849*
GDP	−2.609	−4.319**	−1.934	−4.363*
REC	−2.196	−3.495***	−1.799	−3.520***
TEC	−1.930	−5.201*	−1.479	−5.493*
NREC	−3.197	-4.882*	−1.349	−4.883*

Note: * denotes a 1% level of significance.

Findings and discussion

The brief knowledge of LF, GDP, TEC, REC, and NREC is depicted in Table 1. The variables normality is evaluated using Jarque-Bera test. The results from this test suggest that the variables are distributed normally as shown by the insignificant value of the Jarque-Bera Probability. Moreover, the Kurtosis values for each variable exhibit positive skewness with the exemption of TEC which exhibit negative skewness value. Moreover, the kurtosis value for each indicator is platykurtic in nature. Furthermore, the PP and ADF tests (see Table 2) used for checking the stationarity characteristics of the indicators shows that the variables are I(1).

Next, we check the lag order of variables of research as shown in Table 3. Moreover, LR, FPE, and HQ tests suggests that lag one is the appropriate lag. As a result, this investigation supports the use of lag one.

Result of cointegration

Next, the cointegration between the indicators are evaluated after affirming the lag length which is lag one. We used the bounds test to capture this with the results portrayed in Table 4 showing support for long-run association. This implies that the Ho is refuted and we can conclude that the evidence of cointegration is affirmed between LF and the regressors. Moreover, check the robustness of the ARDL bounds test by using the Bayern & Hanck cointegration with the results shown

TABLE 4 Bounds test.

	F-stat	**T-stat**
LF = f (GDP, NREC, REC, TEC)	7.992*	−5.634*

Note: *$p < 0.01$.

TABLE 5 Bayer−hanck results.

	Fisher stat	**Fisher stat**
LF = f (GDP, NREC, REC, TEC)	EGJOH	EG-JOH-BAN-BOS
	27.746	38.846
	CV	CV
	10.576	20.143

in Table 5. The results corroborate the Bounds test presented in Table 4. Thus long-run association between LF and the regressors is affirmed by both Bounds test and Bayern & Hanck cointegration.

Results of dynamic ARDL

According to the dynamic ARDL estimates (see Table 6), NECR has a detrimental effect on Brazil's EQ over the long and short terms. This shows that even though NREC might boost economic development in many nations, it can also hasten environmental deterioration and thus does not safeguard their ecosystem. Recent studies have shown that NREC has a favorable effect on both environmental deterioration and economic growth in Brazil. The findings did, nevertheless, also show that ecological quality is positively impacted by RENC. This indicates that the environment in Brazil is greatly and positively improved by RENC. Several studies have shown the beneficial effects of RENC in fostering economic development and enhancing ecological integrity, including (Shahbaz et al., 2018; Su et al., 2021; Pan et al., 2022). Brazil must switch from unsustainable and unclean energy to greener, sustainable energy in order to meet the 2030 Agenda for Sustainable Development, in specific SDG 13 and 7. Utilizing renewable energy sources helps lower the

TABLE 3 VAR lag selection criteria.

Lag	LogL	LR	FPE	AIC	SC	HQ
0	111.7055	NA	1.87e-10	−8.208116	−7.966174	−8.138445
1	232.5001	185.8379*	1.23e-13*	−15.57693	−14.12528*	−15.15891
2	255.3586	26.37518	1.85e-13	−15.41220	−12.75084	−14.64583
3	293.6995	29.49301	1.39e-13	−16.43843*	−12.56736	−15.32370*

TABLE 6 Dynamic ARDL results.

	Long-run				Short-run		
	Coefficient	T-statistics	Pvalue		Coefficient	T-statistics	Pvalue
GDP	−0.035*	−4.963	0.000		−0.014***	−2.078	0.054
REC	0.346*	3.635	0.000		0.758**	2.715	0.014
NREC	−0.323**	−2.384	0.028		0.195***	1.983	0.075
TEC	0.024*	3.773	0.000		0.001**	−2.195	0.041
ECT (−1)					−0.727*	−4.834	0.000
C	2.939	3.525	0.002				
R^2	0.87						
Adj R^2	0.85						

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

TABLE 7 Post estimation tests.

Test	X^2	Pvalue
Ramsey RESET Test	0.182	0.857
Normality Test	2.193	0.303
Heteroskedasticity Test	0.051	0.823
Serial Correlation Test	2.678	0.118

FIGURE 4
(A) CUSUM of square. (B) CUSUM of square.

danger of climate change-related events including droughts, flooding and heat waves. Additionally, it can lessen GHGs, lowering health hazards. Additionally, such actions will help to guarantee that people have access to clean, reasonably priced, and dependable energy in keeping with Brazil's goal of achieving sustainable economic growth.

The findings also indicated that, both in the long and short term, the economic growth coefficient is negative and significant. The coefficient in the long-term, nevertheless, is higher than the coefficient in the short-term. This suggests that when economic expansion accelerates, pollution levels do as well. The EKC hypothesis does not apply for Brazil as a result of this compelling evidence against it. These outcomes are in agreement with those of (Pata and Caglar, 2021). Considering that the majority of emerging nations are producers of non-renewable resources, such as fossil fuels, the adverse impact of economic expansion on environmental quality prompts us to think about the key factors influencing economic growth in Brazil. Several studies, including Adedoyin et al. (2021), Acheampong et al. (2022), Chen et al. (2019) and Destek and Sinha (2020) reported similar result.

The use of patents, new technology, or ideas connected to ecological protection might be used to illustrate the positive direct effects of TEC. The creation and use of carbon mitigation solutions is accelerating as carbon emissions and climate change are receiving more and more prominence.
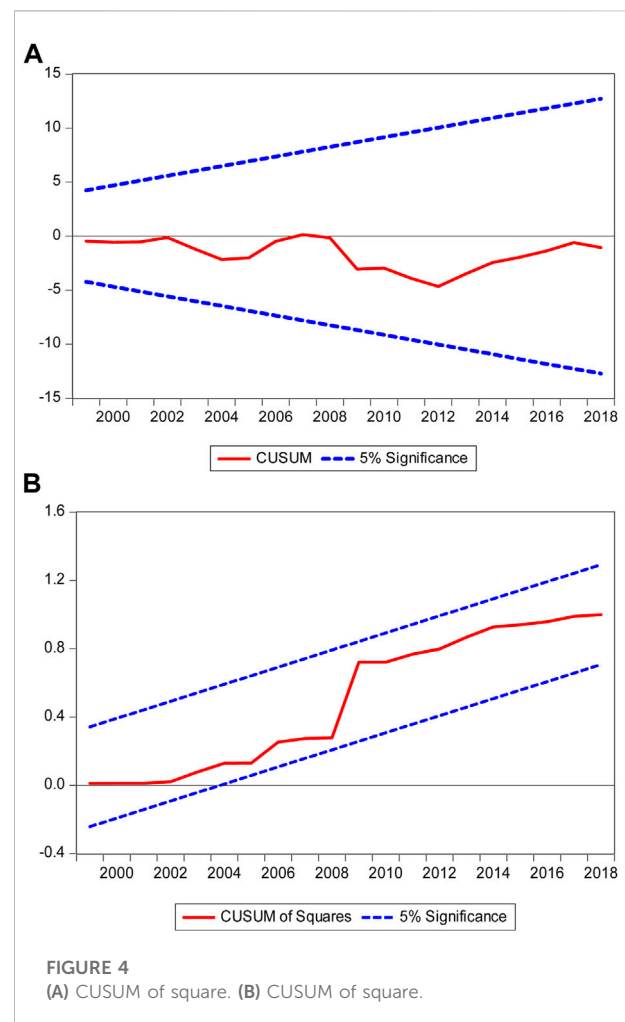
These include green chemistry methods, carbon fixation technology, power generation, combined heat, carbon capture and storage technology, sustainable green construction concepts,
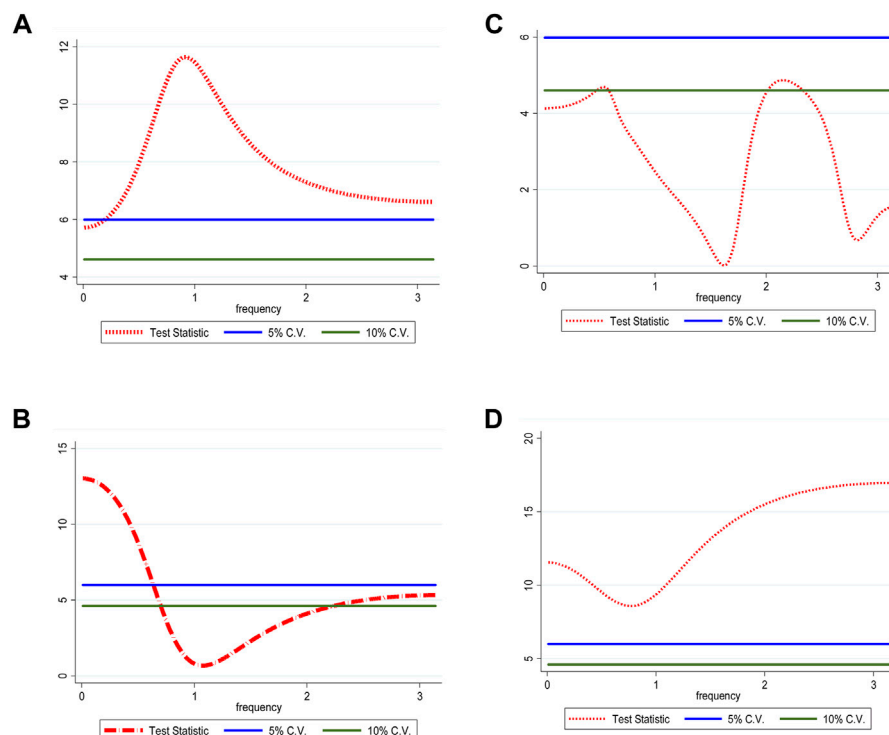
FIGURE 5
(A) Causality from REC to LF. **(B)** Causality from GDP to LF. **(C)** Causality from TEC to LF. **(D)** Causality from NREC to LF.

and more. Both prior literature and practical use have supported the strategies' reducing effects. Some of these methods were being used widely in Brazil. Therefore, technological progress has a favorable effect on Brazil's ecological quality (Altuntaş et al., 2022; Ojekemi et al., 2022).

The error 'correction term (ECT) is used to gauge adjustment speed. At a 1% level of statistical significance, the value of is statistically negative and significant, as predicted. According to ECT, the prior equilibrium is changing at a rate of about 0.72% every year. The explanatory variables utilized in the research accurately represent a variance of 87% in the predictor variables, according to the measured R^2 value. The observed p-value of F-statistics provides support for the research's model's proper fitting. The diagnostics tests result also affirm no problem of serial correlation, residuals are distributed normally, and no misspecification in the model (see Table 7). Furthermore, the model stability is affirmed by the CUSUM and CUSUMSQ (See Figures 4A,B).

Causality test outcomes

The last phase entails the causality between load capacity factor and the regressors such as RENC, GDP, NREC, and TEC. The results obtained disclosed interesting findings. In the long-

term, renewable energy (Figure 5A), economic growth (Figure 5B), technological innovation (Figure 5C) and nonrenewable energy (Figure 5D) Granger cause LCF suggesting that the regressors can forecast the environmental quality in Brazil.

Conclusion and policy recommendations

Conclusion

This paper focuses on the effects of disintegrated energy and technology innovation on load capacity factor in Brazil using data between 1990 and 2018. We used dynamic ARDL and frequency domain causality approaches to investigate these linkages in order to prevent potentially false results and to learn more about the association. The results of the dynamic ARDL disclosed that economic growth and non-renewable energy impact environmental quality negatively while technological innovation and green energy impact environmental quality positively. Furthermore, the frequency domain causality is used to evaluate the causal effect of RENC, EG, TEC and NREC on environmental quality. The results obtained disclosed interesting findings. In the long-

term, RENC, EG, TEC and NREC Granger cause LCF suggesting that the regressors can forecast the environmental quality in Brazil.

Policy implications

These results have a number of policy repercussions for Brazil, particularly in light of the pandemic. Programs for palliative care and support must include strategies for quickening the creation and spread of renewable energy resources and technologies. In order to maintain the gains obtained thus far as well as to enhance sector and employment activities, the Brazilian government must raise its investments in renewable energy. To boost efficacy, sustainability and efficiency, these expenditures might include adding more wind power generators and solar, taxing fossil fuels sources more heavily, and giving priority to maintaining nuclear and hydroelectric power plants. Research and development on how to enhance energy systems should also delve at innovative systems.

The government need to support innovations that increase energy efficiency. Therefore, the government need to support and encourage the use of this technology. The restrictions preventing the spread of technology should be lifted by the government. Additionally, the employment of clean technologies, including alternative energy sources, recycling and waste technologies, management technologies, and the discharge of GHGs and energy storage may help customers lead a better lifestyle. Innovative use of green technology in industry may have an influence on society, the environment and economy. To promote ecological disposal and product development skills, the government may invest in ecological conservation and green technology innovation. Policymakers in Brazil may keep creating environmentally friendly technologies, expand bilateral cooperation, and create a win-win situation in the area of ecological protection. In addition, the government may support the commercialization of patents and their transformation into innovation and productivity, notably in the fields of renewable energy and climate change mitigation. Brazil may take the ecosystem's effect into account while raising its technological innovation levels and direct the development of green technologies. As a result of political, social and economic globalization, ecological protection issues may also be discussed in greater detail with other high-technology nations, and their individual technical strengths may be used to promote cooperative technological innovation transition.

Similarly, it would be beneficial for decision-makers to fund energy efficiency initiatives and conduct public-private partnership investments (PPPI) to advance innovative, sustainable energy and other comparable investments. So, in an ideal public-private partnership, the public sector would offer the private sector financial incentives for participating in climate change mitigation initiatives, thereby reducing global warming. The public-private collaboration may support investments in climate adaptation across a range of industries, particularly energy. As a result, investing in public-private partnerships may both reduce ecological damage while also fostering economic progress.

Limitations and potential future study areas

In the instance of Brazil, the present study produced significant research evidences, however our approach contains several shortcomings that might be fixed in future studies. The lack of data on the load capacity factor accessible after the research period restricts the effectiveness of the econometric approaches utilized, which is one of our research' major flaws. Nevertheless, this research evaluated how technological innovation, disintegrated energy usage, and economic expansion dynamically impacted load capacity factor in Brazil. Additional research can examine the possibility of additional factors that can reduce emissions, including switching to organic produce, extending wooded areas, recycling products, and curbing water and electricity use, etc. Lastly, other studies should be conducted in other emerging and developed nations.

Data availability statement

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

Funding

Acknowledgments

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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