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Asymmetric Role of Economic Growth, Globalization, Green Growth, and Renewable Energy in Achieving Environmental Sustainability

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Abstract

This study fills the gap in the literature by applying novel quantile regression and spectral Granger causality frameworks to evaluate the asymmetric effect of GDP, globalization, green growth, and renewable energy consumption on CO_2 emissions in India. The results suggest that in all quantiles, green growth, globalization, and renewable energy consumption impact environmental quality negatively, and the effect of economic growth on CO_2 emissions is positive in most of the quantiles. In addition, the nexus between the regressors and CO_2 emissions is significant across different time horizons. More specifically, the results from the spectral Granger causality test unveil that all the indicators would predict CO_2 emissions across various time scales. Several policy implications have been proposed based on the research's findings so that India might move toward achieving sustainable development.

Keywords:

Green Growth; Renewable Energy; Globalization; CO_2 Emissions; Quantile Regression.

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1- Introduction

The main greenhouse gas responsible for both environmental pollution and climate change brought on by humans is carbon dioxide [1]. As a result, cutting CO_2 emissions has risen to the top of the global policy agenda for nations. In addition, green growth, or ecologically sustainable economic growth, is regarded as a critical method for attaining long-term development [2, 3]. Globally, governments view preserving environmental sustainability while achieving economic growth as a key objective of policy [4]. The advancement of green technology is essential to lowering CO_2 emissions and fostering green economic growth [5]. CO_2 emissions are a big concern not only for India but for the entire world, with the introduction of many technological innovations and ever-progressing economic growth with rising clean energy. Therefore, sustainable economic growth has been a major challenge in India.

In terms of the key economic drivers for increased carbon emissions, renewable energy consumption, green growth, and globalization may be the most likely possibilities for declining CO_2 emissions and other greenhouse gases [6]. As a result, in both developing and advanced nations, numerous researchers have looked into the connection among these indicators. Remarkably, the empirical analysis does not support the conclusions drawn in the earlier study, which could be attributed to variations in the economic structures and statistical techniques used by researchers [7]. Hence, further research on the topic using novel techniques is required to generate more accurate findings. Put differently, this study aims to assess the asymmetric role of economic growth, globalization, green growth, and renewable energy in achieving environmental sustainability in India, which is one of the most polluting countries across the world. India contributed 6.81% of the global carbon dioxide emissions in 2015, according to the Emission Database for Global Atmospheric Research.

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India is the subject of this empirical study for some reasons. First, as per the Global Carbon Project, CO_2 emissions in India increased by 6.3% on average in 2018 [8]. More importantly, India is the third-largest emitter of CO_2 behind the United States and China [7]. As part of the manufacturing process, limited gas exploitation and oil reserves degrade environmental quality. As a result, it is necessary to explore the nexus between CO_2 emissions and economic development in this country. In order to protect the environment, a global rise in the proportion of renewable energy in overall energy usage profiles is required by the seventh Sustainable Development Goal of the United Nations. India must pay more attention to green investments such as green growth and renewable energy. Hence, more investigation is required to determine how macroeconomic determinants affect environmental quality in India to achieve sustainable development.

The prime objective of this study was to investigate the asymmetric impact of economic growth, globalization, green growth, and renewable energy on CO_2 emissions in India to highlight novel conclusions and results. In other words, by applying quantile econometric methodologies, our work seeks to clarify the asymmetric association between GDP, globalization, green growth, renewable energy consumption, and environmental quality, i.e., the quantile cointegration test with constant cointegrated coefficients developed by Xiao [9], quantile-on-quantile regression suggested by Sim & Zhou [10], and the spectral Granger causality offered by Breitung & Candelon [11].These methodologies give systematic explanations about the association between the examined indicators and can indicate intricate behavioral patterns. The comprehension of complicated linkages, heterogeneity, asymmetric impacts, and nonlinear relationships between economic growth, globalization, green growth, renewable energy, and CO_2 emissions is improved by the use of QQR and spectral Granger causality techniques. By using these techniques, time series analysis as a whole is able to more thoroughly and precisely evaluate sustainability and environmental issues.

Green growth initiatives can help achieve both long-term economic growth and lower energy use [1, 6]. Any economy's economic growth and progress can be jeopardized by environmental damage. According to numerous studies, emerging nations are eradicating poverty through conventional growth; however, it is unclear what strategies they have in place for green growth and the shift to a sustainable growth path that will lead to a clean environment [3, 5, 6, 12, 13]. More crucially, many scholars have paid less attention to renewable energy and green growth, as well as their effects on CO_2 emissions. Therefore, additional research is needed to determine the influence of globalization, green growth, and renewable energy sources on CO_2 emissions.

Prior studies looked at certain facets of CO_2 emissions, renewable energy, and economic development [3, 12-15]. However, none of the studies clarified the asymmetric relationship between them, which inspired and enabled us to choose factors related to globalization, renewable energy, and green growth for our study project. The empirical results of this work greatly aid in the creation and application of policies that provide new and thorough explanations of how economic growth, globalization, green growth, renewable energy, and CO_2 emissions are all interdependent in India. Furthermore, the present method yields more precise and trustworthy information on these variables and provides valuable information about the interactions between various economic growth, globalization, green growth, renewable energy, and CO_2 emissions quantiles.

The existing literature on the interaction between energy usage, GDP, and globalization has mainly centered on the overall influence of economic development without adequately considering the elements of renewable energy use and green growth [2, 4]. While some articles have examined the interplay between renewable energy and CO_2 emissions, there remains a significant gap in understanding the specific contributions of green growth to this association, especially in India. Understanding the interplay of macroeconomic issues and green growth in this country is critical given its significant CO_2 emissions and contribution to global warming. Hence, a fully understanding of the relationship between these indicators in India is essential. Therefore, more studies are required to look into the precise impact of GDP, globalization, green growth, and renewable energy on CO_2 emissions.

There are five sections to this study. A literature review is presented in Section 2. Section 3 presents techniques. Results are presented in Section 4. Section 5 concludes.

2- Literature Review

In the body of existing research, a number of studies have looked at the interplay between GDP, carbon emissions, globalization, green growth, and renewable energy. Nevertheless, the findings of past articles are mixed and inconclusive. According to Aslam et al. [16], commerce, industry, and population density all raise CO_2 emissions in China, but over time, economic growth decreases CO_2 emissions. Additionally, it discovered a one-way relationship between trade openness structure and population density and a bidirectional causal link between CO_2 emissions and industrialization. In Kuwait, Wasti & Zaidi [17] analyze the interplay between energy consumption, CO_2 emissions, trade liberalization, and economic growth.

The authors reveal that energy consumption and CO_2 emissions both stimulate economic expansion; a rise in CO_2 emissions also has a major impact on rising energy consumption. Pejović et al. [18] propose several key ideas, including the following: there is no proven causal relationship between GDP and renewable sources for the 27 EU member states;

there is a bidirectional correlation between GDP and CO_2 emissions; and there is a bidirectional negative nexus between CO_2 emissions and renewable sources. Similarly, Munir et al. [19] discover one-way Granger causality from GDP to CO_2 in Thailand, the Philippines, Malaysia, and Singapore; one-way causality from GDP to energy consumption in Indonesia, Malaysia, and Thailand; a unidirectional relationship from EC to GDP in Singapore; and bidirectional causality between GDP and energy consumption in the Philippines in ASEAN countries.

Globalization has considerably aided the integration of national economies, cultures, technologies, and governments and has resulted in intricate mutual interdependence relationships as national borders have eroded [20, 21]. Global concerns have been voiced concerning the environmental impact of the fast integration of distant economies [22]. The environmental impact of globalization continues to be a contentious issue among politicians and scholars. Gaies et al. [1] confirm an asymmetric long-run influence of economic globalization on CO_2 emissions in MENA countries. According to Li et al. [20], globalization and green investment have a significant long-term impact on reducing carbon dioxide emissions in MINT countries. They also examine the effects of GDP, non-renewable energy consumption, technological innovation, and globalization on CO_2 emissions. Huo et al. [23] analyze the influence of economic globalization on developed-country carbon emissions from 1970 to 2019. The findings indicate that strong positive associations exist between globalization, economic growth, coal consumption, and CO_2 emissions. As per Jahanger [21], globalization on the political and economic fronts considerably lessens environmental damage, but globalization on the economic, social, and general levels degrades environmental quality. Similarly, Acheampong [22] reveals that positive and negative changes in political globalization increase CO_2 emissions in the long run, whereas positive and negative changes in social globalization decrease CO_2 emissions in Ghana.

Some previous papers have centered on India. Pachiyappan et al. [8] employ ARDL to investigate the interplay between GDP, CO_2 emissions, population, and energy consumption increases in India. The findings indicate the presence of a long-term equilibrium nexus as well as bidirectional causality between the variables. Mehmood et al. [24] further demonstrate that the nexus between institutional quality and GDP on CO_2 emissions in this country is different. In the same vein, Jayasinghe & Selvanathan [25] add to the Indian research on the nexus between economic growth, energy consumption, and CO_2 emissions by confirming that energy use and tourism both contribute positively to CO_2 emissions. Although Khochiani & Nademi [7] show a strong positive relationship between CO_2 emissions and GDP, it is unclear how GDP and energy consumption are related. According to Ahmed et al. [14], energy consumption affects CO_2 emissions in India the most, whereas renewable energy has the least effect.

Kuldasheva & Salahodjaev [26] reveal that renewable energy reduces carbon dioxide emissions. Rehman et al. [27] suggest that negative globalization and economic growth shocks have both short- and long-term beneficial and negative effects on CO_2 emissions. Similarly, Balsalobre-Lorente et al. [28] report that economic development contributes positively but lesseningly to environmental degradation, meeting the EKC to the extent that long-term CO_2 emission neutrality is possible. Adebayo & Ullah [29] highlight a negative relationship between energy efficiency measures and CO_2 emissions in different timescales in Sweden. Usman [30] suggests that spending on green energy technologies and renewable energy has a varied and adverse impact on CO_2 emissions. Madaleno & Nogueira [31] demonstrate that trade, human development, and gross fixed capital all positively contribute to economic expansion. However, while the use of renewable energy increases these contributions, it does so at the expense of increased CO_2 emissions. For every BRICS nation, the interplay between CO_2 emissions and energy consumption is substantial and positive [32]. According to Mamkhezri & Khezri [33], renewable energy usage reduces CO_2 emissions in both the short and long run.

Uzair Ali et al. [15] provide data in support of the environmental Kuznets curve theory, which maintains that there is a U-shaped link between CO_2 and economic development, in their examination of the impacts of population density, economic development, and fossil fuel usage on CO_2. Crucially, CO_2 has a negative impact on GDP, whereas fossil fuels, FDI, and overall exports have all had a positive influence on GDP in the long run. The dynamic interactions between economic growth, energy consumption, and CO_2 emissions are determined by Kang et al. [34]. They also uncover the time-varying patterns of the influence transmission mechanisms between these indicators. Specifically, Qayyum et al. [12] analyze the relationship between CO_2 emissions and financial instability and suggest that there is a considerable nexus between these variables. Additionally, long-term causality is seen in energy use, urbanization, CO_2 emissions, and financial instability. Likewise, according to Ozcan & Ulucak [13], increasing nuclear energy instantly lowers environmental pollutants, indicating that adding more nuclear power to India's energy mix would help mitigate climate change.

One of the best substitute strategies for long-term development is now green growth. The origins of studies on green growth and carbon emissions can be traced back to the argument over the causal relationship between economic expansion and CO_2 emissions. Several scholars agree that quick economic growth has a major influence on CO_2 emissions [5, 35]. Zhao et al. [2] suggest that green growth negatively influences CO_2 emissions in China. The theoretical assumption that green growth protects environmental quality in G7 economies is supported by Hao et al. [3]. In the context of Asian economies, Saleem et al. [36] argue that GDP, green growth, and technical advancement all have a substantial impact on CO_2. Similarly, Ulucak [4] investigates the influence of environmental technology on green growth

by managing renewable and non-renewable energy consumption in BRICS countries and finds that environmental-related technologies contribute favorably to green growth. Tawiah et al. [6] posit that economic development positively influences green growth, while trade openness is detrimental to green growth in developing countries. The literature review indicates that energy consumption, globalization, green growth, and GDP all contribute significantly to the explanation of CO_2 emissions in the majority of countries. However, the statistical significance of these factors varies amongst studies based on the data and time period employed in the empirical analysis. Even though the topic has been the subject of numerous traditional time series studies conducted in India, more research with current data is needed for effective policy formulation given the country's rate of economic growth, level of energy consumption as a result of the size of renewable energy consumption, and green investment. In order to fill this knowledge vacuum, our current study significantly adds to the body of literature on this subject, particularly in the context of India.

3- Research Methodology

3-1- The Quantile-on-Quantile Regression (QQR)

A nonparametric quantile regression approach is utilized to examine how various quantiles of macroeconomic factors (X) impacted different quantiles of CO_2 emissions (Y). The Equation is presented as follows:

$$Y_t = \beta^{\theta}(X_t) + \varepsilon_t^{\theta} \quad (1)$$

where Y_t shows the dependent variable in period t and X_t represents the independent variables in time t. θ is the θ^{th} quantile on the distribution of X. Additionally, ε_t^{θ} represents quantile error term, where estimated θ^{th} quantile is equal to zero. $\beta^{\theta}(.)$ is an unknown parameter we do not have past information in relation to the relationship between X and Y. Therefore, we use a first-order Taylor expansion of $\beta^{\theta}(.)$around a quantile of $X^{\theta}$to linearize the function $\beta^{\theta}(.)$, which can be expressed as follows:

$$\beta^{\theta}(X) \approx \beta^{\theta}(X^{\tau}) + \beta^{\theta'}(X^{\tau})(X_t - X^{\tau}) \quad (2)$$

where $\beta^{\theta'}$ is the partial derivative of $\beta^{\theta}(X_t)$.

Additionally, Sim & Zhou [10] noted that Equation 1 can be simplified as follows:

$$Y_t = \beta_0(\theta, \tau) + \beta_1(\theta, \tau)(X_t - X^{\tau}) + \varepsilon_t^{\theta} \quad (3)$$

The choice of bandwidth is particularly important when doing a nonparametric analysis because it influences the speed of the results and simplifies the objective point. The variance declines while the deviation of estimation reduces when the bandwidth h is set to a big value, and vice versa. Hence, in this study, the bandwidth value of h = 0.05 was adopted, as recommended by Sim & Zhou [10].

3-2- Spectral Causality

We prefer to use the frequency causality test that Breitung & Candelon [11] established. The two linear limitations listed below form the foundation of this strategy.

$$\sum_{k=1}^{p} \delta_{12,k} \cos(kw) = 0 \quad (4)$$

$$\sum_{k=1}^{p} \delta_{12,k} \sin(kw) = 0 \quad (5)$$

The VAR equation for X_t can be given by the following expression:

$$X_t = a_1 X_{t-1} + \cdots + a_p X_{t-p} + \beta_1 Y_{t-1} + \cdots + \beta_p Y_{t-p} + \varepsilon_t \quad (6)$$

with given by:

$$\mathrm{R}(\omega) = \begin{bmatrix} cos(\omega) & cos(2\omega) & \dots & cos(p\omega) \\ sin(\omega) & sin(2\omega) & \dots & sin(p\omega) \end{bmatrix} \quad (7)$$

and $\beta = (\beta_1, \dots \beta_p)'$, the hypothesis "Y does not cause X at frequency ω", that is $M_{Y \to X}(\omega) = 0$ is equal to the following linear restriction.

$$H_0: R(\omega)\beta = 0 \quad (8)$$

The ordinary F statistic for testing of the null hypothesis described is approximately distributed as for $\omega \in (0, \pi)$. Figure 1 shows the flow of analysis.

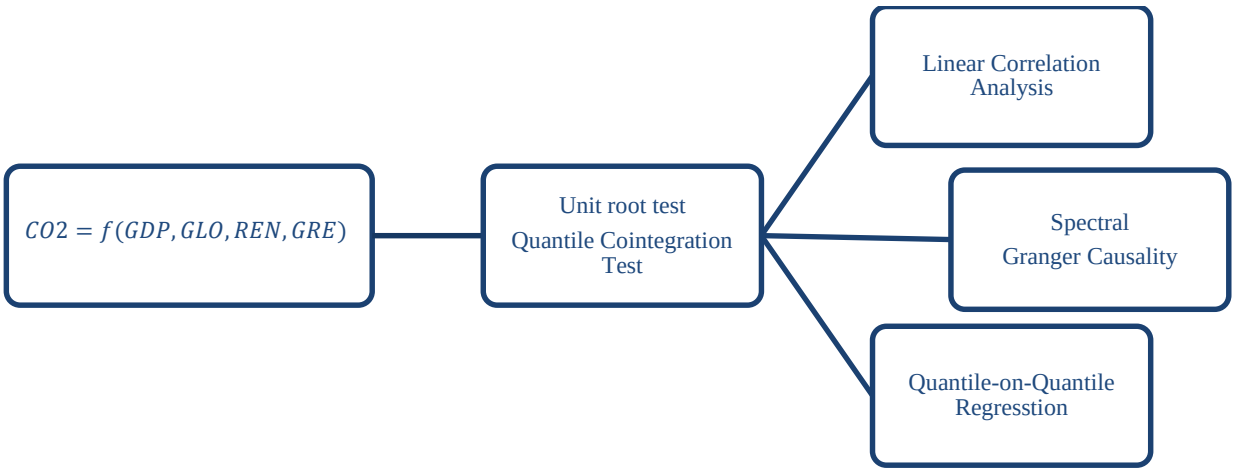

Figure 1. Flow of analysis

4- Data

To assess the role of renewable energy (REN), green growth (GRE), economic growth (GDP), and globalization (GLO) in limiting CO_2 emissions (CO_2) in India, this research employs data from 1990 to 2022. The independent variables are GRE, REN, GDP, and GLO, while the dependent variable is CO_2. The sources of the variables and related measurements are presented in Table 1. Following previous research, the data was changed from low-frequency to high-frequency data [37]. In addition, these variables are logged to deal with outliers.

Table 1. Indicators sources and measurement

Variables	Code	Measurement	Source
CO_2 emissions	CO_2	Million ton per capita	WDI (2023)
Globalization	GLO	KOF combined political, social and economic index	KOF Swiss Economic Institute
Economic growth	GDP	Per capita GDP at constant US$ 2010	WDI (2023)
Renewable energy consumption	REN	% of total final energy usage	WDI (2023)
Green growth	GRE	Index of EAMFP	OECD

The descriptive statistics in connection with all interested indicators are illustrated in Table 2. The summary snapshot suggests that the average value of GDP is highest, while the value of CO_2 is negative. This is accompanied by REN (0.930453), GLO (0.984221), and GRE (0.324401). The standard deviation of economic growth is the highest, while CO_2 is less volatile than other time series. With the exemption of GRE and GDP, CO_2, REN, and GLO are negatively skewed. Additionally, the selected indicators have positive kurtosis, and their coefficients are less than 3. Also, the Jarque-Bera value reveals that all-time series under investigation conform to normality at the 1% significant level. The selected examination in India from 1990 to 2022 is described in Figure 2.

Table 2. Descriptive statistics of sample exchange rate returns

	CO_2	REN	GLO	GRE	GDP
Mean	-0.284212	0.930453	0.984221	0.324401	1.731635
Maximum	-0.240905	0.994454	1.036262	0.406889	1.915381
Minimum	-0.343614	0.870572	0.862590	0.249713	1.566999
Std. Dev	0.025866	0.041759	0.055536	0.050282	0.110174
Skewness	-0.365316	-0.063238	-0.825785	0.437123	0.091599
Kurtosis	2.355523	1.413793	2.299955	1.749251	1.674631
Jarque-Bera	5.220460***	13.92626***	17.69760***	12.80774***	9.845903***

Notes: *** Statistical significance at 10% level

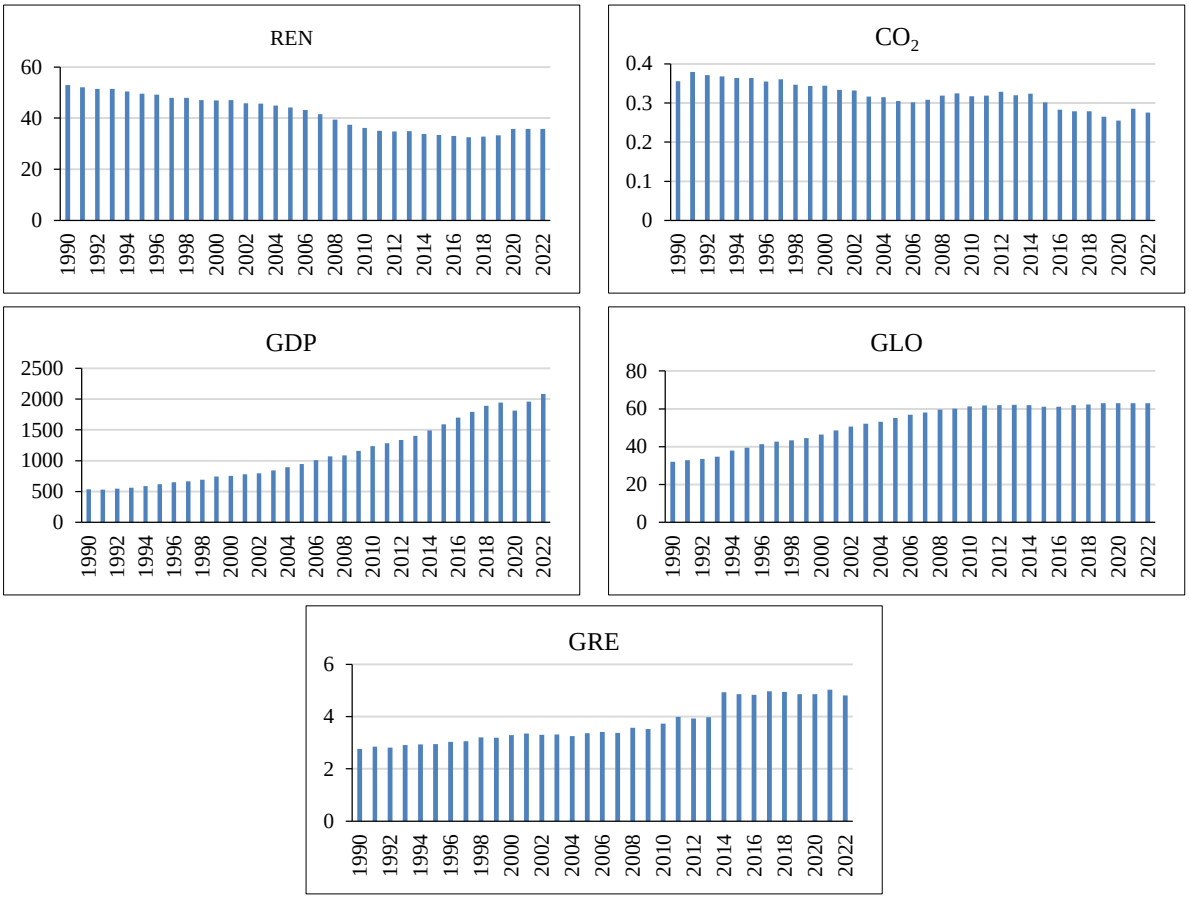

Figure 2. Plots of the examined indicators

The pairwise correlation between pairs of indicators is computed, and the heatmap is represented in Figure 3. The findings suggest that the unconditional linear correlations between CO_2 emissions and other selected variables are strongly negative. It is clear that the indicators in this paper have a strong relationship that further allows employing quantile econometric approaches to draw the outcomes.

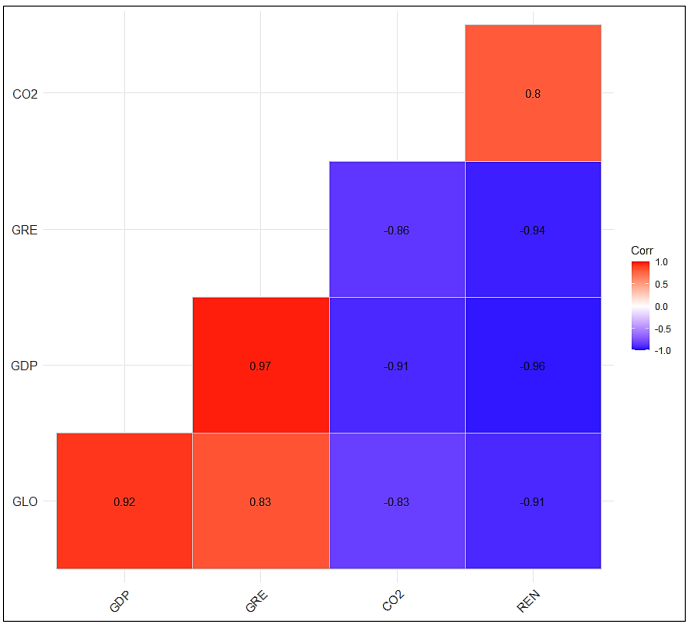

Figure 3. Heatmap correlation matrix

In the accompanying phase, the current study performed a unit root test on distinct quantiles to check the stationary qualities in India. The quantile unit root test is utilized to construct the stationary properties of CO_2 emissions, GRE, REN, GDP, and GLO. Table 3 shows the persistence coefficients, t-statistic, and critical values ($\hat{\alpha}$) of a grid system of

19 quantiles ranging from 0.05 to 0.95 obtained from the quantile unit root test. The results indicate that the t-statistic coefficients of the conditional distribution quantiles are all smaller than the critical value, thereby rejecting the null hypothesis that the variables have no unit root. In line with the findings of Sharif et al. [37], the quantile unit root test confirms indicators are non-stationary at the level of data. Therefore, we can conclude that all-time series are nonstationary because the t-statistic is less than the crucial value numerically.

Table 3. Quantile Autoregression Unit Root Analysis

τ	CO_2		REN		GLO		GRE		GDP	
	$\hat{\alpha}$	t-statistic	$\hat{\alpha}$	t-statistic	$\hat{\alpha}$	t-statistic	$\hat{\alpha}$	t-statistic	$\hat{\alpha}$	t-statistic
0.05	-3.2893	1.1421	-2.5898	0.7940	-2.3100	-1.2803	-2.6507	0.6998	-2.6767	2.3642
0.10	-2.9463	1.7316	-3.4100	0.9277	-2.6548	-2.4631	-2.3386	1.4652	-2.6745	1.1119
0.15	-2.7677	2.6712	-3.4100	2.8831	-2.7081	-0.5966	-2.7734	0.0682	-2.7111	7.8251
0.20	-2.9407	-1.8218	-3.4100	-0.1532	-2.5461	-0.3724	-2.5205	0.0527	-3.2161	-1.1804
0.25	-2.8177	-1.7786	-3.3773	0.2630	-2.9698	0.1473	-2.3100	0.0322	-3.0664	-1.4743
0.30	-2.8848	-2.5730	-3.4100	-0.5778	-2.9420	-0.4054	-2.3100	-0.1614	-2.7758	-1.3128
0.35	-3.1130	-2.2680	-3.3769	-0.0653	-3.0154	-0.2963	-2.7502	-1.0730	-3.1754	-1.6120
0.40	-2.8198	-1.6655	-3.3422	-0.1111	-2.8773	-0.2214	-2.6624	-1.1180	-3.2600	-1.5923
0.45	-3.0864	-0.8426	-3.3706	0.1047	-2.9557	-0.1386	-3.0060	-1.4478	-3.1928	-2.3659
0.50	-2.8051	-0.8212	-3.3940	0.0305	-2.9800	0.1378	-2.3100	-1.3747	-3.2469	-3.0622
0.55	-3.0974	-1.3363	-3.1748	0.1263	-2.7155	0.2393	-2.3100	-1.6198	-2.7521	-1.9153
0.60	-3.2648	-1.1322	-3.2910	0.1498	-2.7325	0.2341	-2.9946	-2.3733	-2.9447	-1.8527
0.65	-3.1363	-1.4962	-3.2389	-0.3558	-2.3100	-0.2436	-3.1641	-2.4084	-3.1052	-2.1502
0.70	-3.2343	-1.4270	-3.0183	-0.2344	-2.3100	0.1098	-2.8639	-0.9102	-2.7411	-1.6734
0.75	-2.8676	-2.1872	-3.1692	-0.2258	-2.3100	-0.0374	-2.7847	-0.9094	-2.8324	-2.4532
0.80	-2.8852	-2.8996	-3.2439	-0.0940	-2.4313	-1.2563	-2.3528	-0.6808	-2.7841	-2.6797
0.85	-2.7057	16.8936	-2.9601	3.0831	-2.3100	3.8334	-3.3137	9.5460	-2.3100	1.7391
0.90	-2.6494	3.5010	-3.2725	-0.8398	-2.3100	3.4269	-2.8465	3.7309	-2.3100	1.3627
0.95	-2.9249	1.8062	-3.0553	3.9511	-2.3100	1.5107	-3.4100	8.3808	-2.3100	0.6722

Notes: The table presents point estimates-statistics and critical values for the 5% level of significance. If the t-statistic value is less than the critical value, then the null hypothesis of $\beta(\pi) = 1$ is rejected at the 5% level.

Here, the fluctuating co-integration connection between CO_2, GRE, REN, GDP, and GLO was corrected through the application of the quantile co-integration technique, as first presented by Xiao [9]. Table 4 shows the quantile cointegration results for these couples in India. It denotes that the supremum norm value of the β and γcoefficients, as well as CV1, CV5, and CV10, are the key statistical significance values at 1, 5, and 10%, respectively. Overall, it is evident that the supremum norm values of the β and γcoefficients are larger than all the critical values at 1%, 5%, and 10% independently, which means that there is a considerable long-term association between CO_2 and other related variables in India. Similar to Sharif et al. [37] quantile cointegration results revealed the existence of a basic nonlinear long-run relationship among the variables investigated.

Table 4. Quantile Cointegration Test

Model	Coefficient	Supτ | $V_n(\tau)$ |	CV1	CV5	CV10
CO2-REN	β	3210.98	2899.06	10128.31	900.87
	γ	457.47	435.82	316.53	214.53
CO2-GLO	β	61.94	53.42	14.32	10.34
	γ	14.20	11.54	9.05	5.26
CO2-GRE	β	9410.31	8547.61	8045.38	7081.20
	γ	6512.52	6214.19	2310.25	2014.27
CO2-GDP	β	105.45	97.24	90.14	60.24
	γ	325.47	258.24	45.61	29.14

Note: This table presents the results of the quantile cointegration test for the logarithm of the selected variables and economic sustainability. We test the stability of the coefficients β and γ in the quantile cointegration model, and CV1, CV5, and CV10 are the critical values of statistical significance at 1%, 5%, and 10%, respectively.

5- Results

In this section, we provide an empirical investigation in connection with the nexus between CO_2 emissions and green investment and further analyze the potential impacts of macroeconomic factors on this association across different economic conditions. By doing this, we investigate the asymmetric and nonlinear relationship of CO_2 emissions with green investment over the joint data distribution of dependent and regressor indicators realized by the QQR techniques. The outcomes of the QQR method are represented in Figures (3-a) to (4-d). The graphical depiction for India is shown in this figure, with the z-axis showing the cross-tabulated coefficient of the QQR and the x-axis representing per capita CO_2 emissions, REN, GLO, GDP, and GRE. Put differently, these plots depict the long-term asymmetric impact of REN, GRE, GDP, and GLO on CO_2 emissions in India at different quantile distributions. Figures 3-a to 4-d uncover the slope coefficient estimate, $\beta 1(\theta, \tau)$, which captures the effect of the τ^{th} quantile of selected regressor variables on the θ^{th} quantile of CO_2 emissions at different values of θ and τ for India.

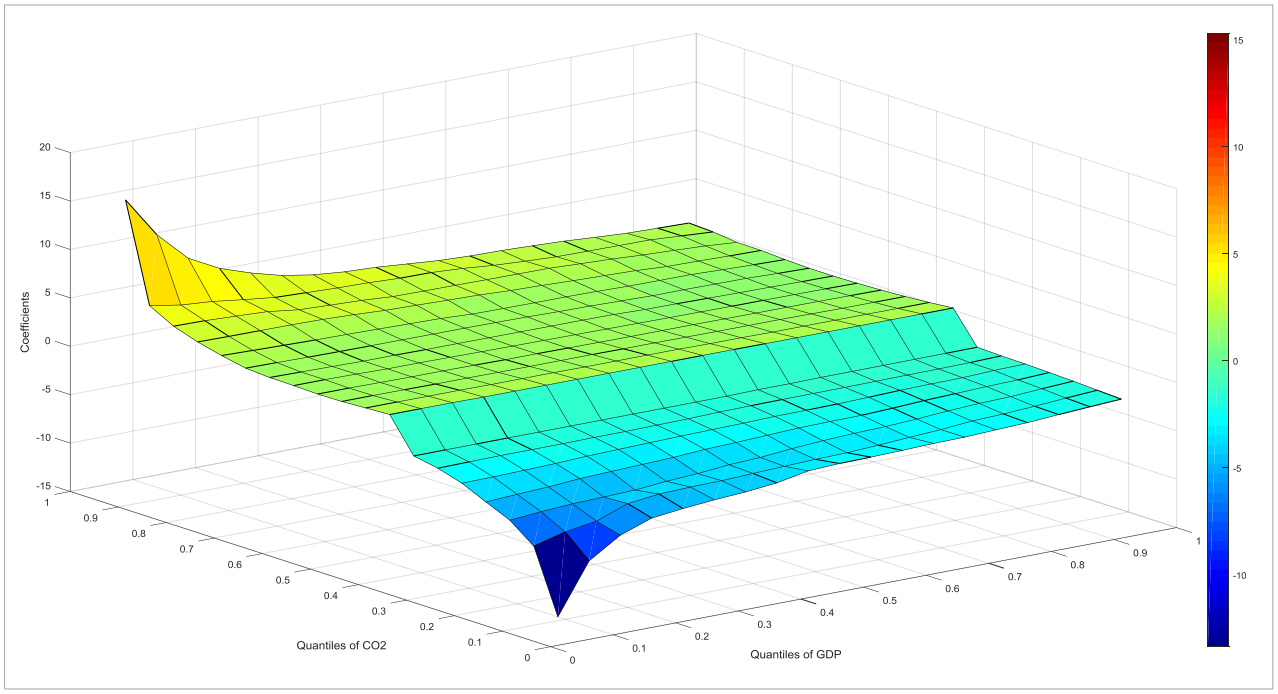

Figure 4a. Impacts of GDP on CO_2 emissions

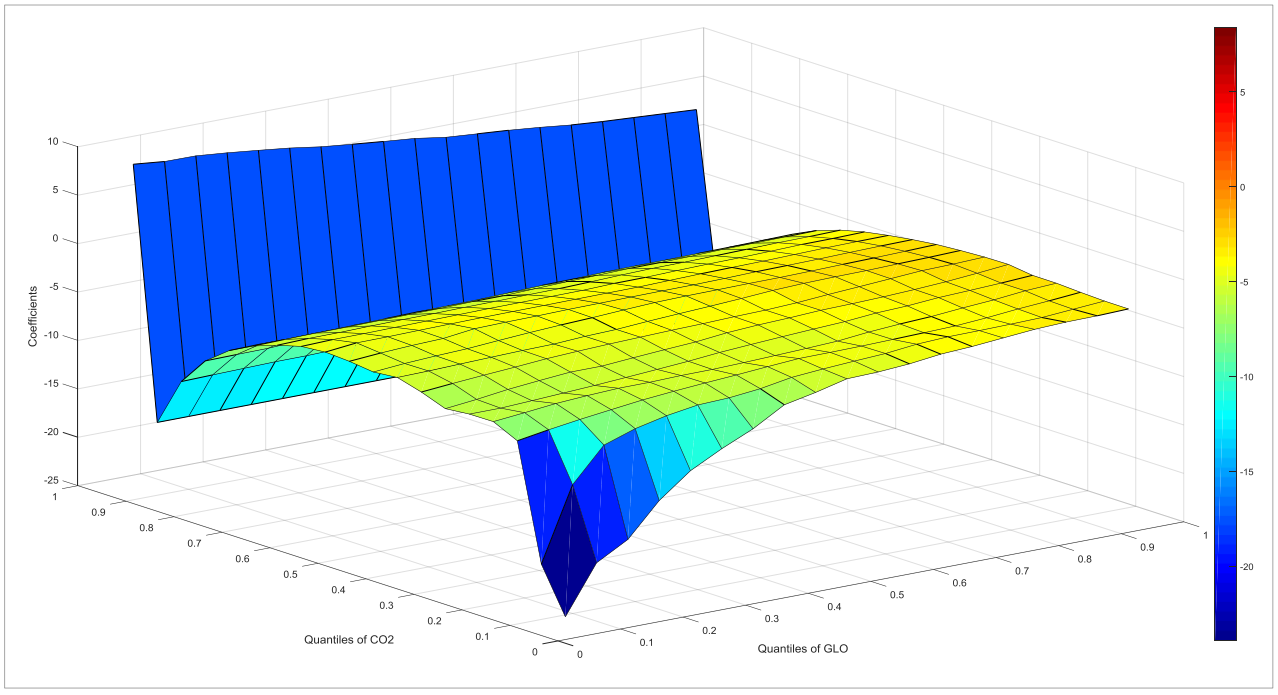

Figure 4b. Impacts of GLO on CO_2 emissions

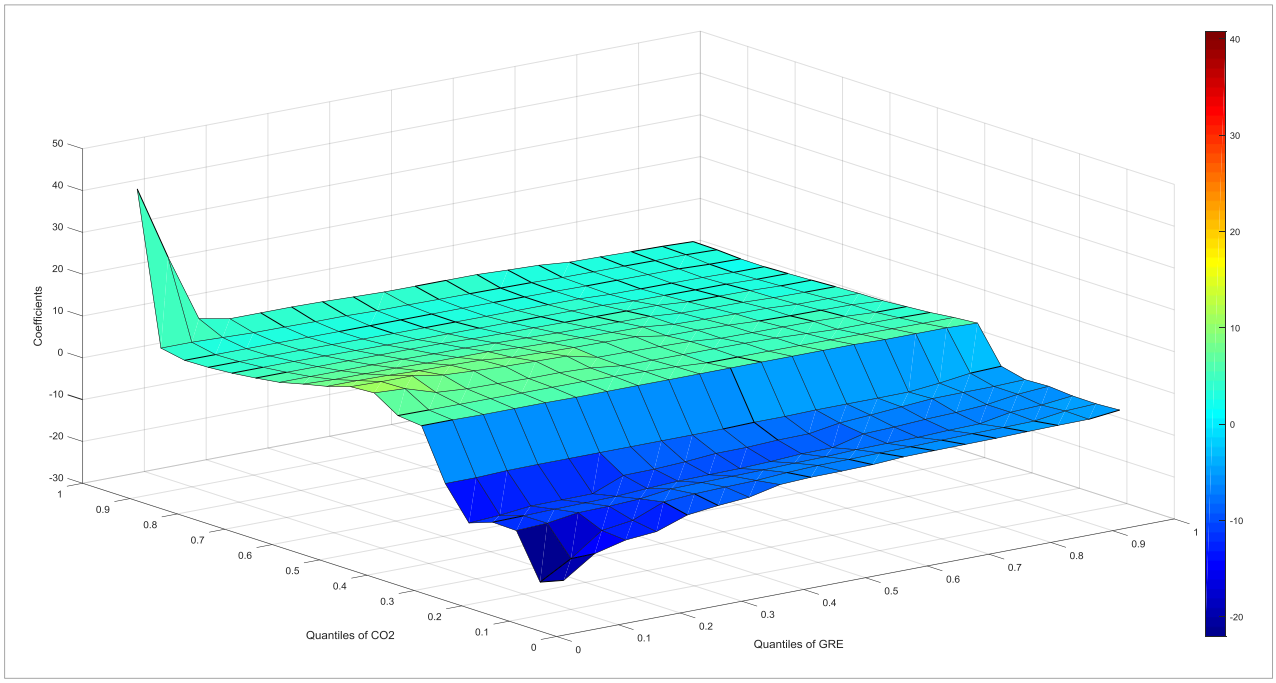

Figure 4c. Impacts of GRE on CO_2 emissions

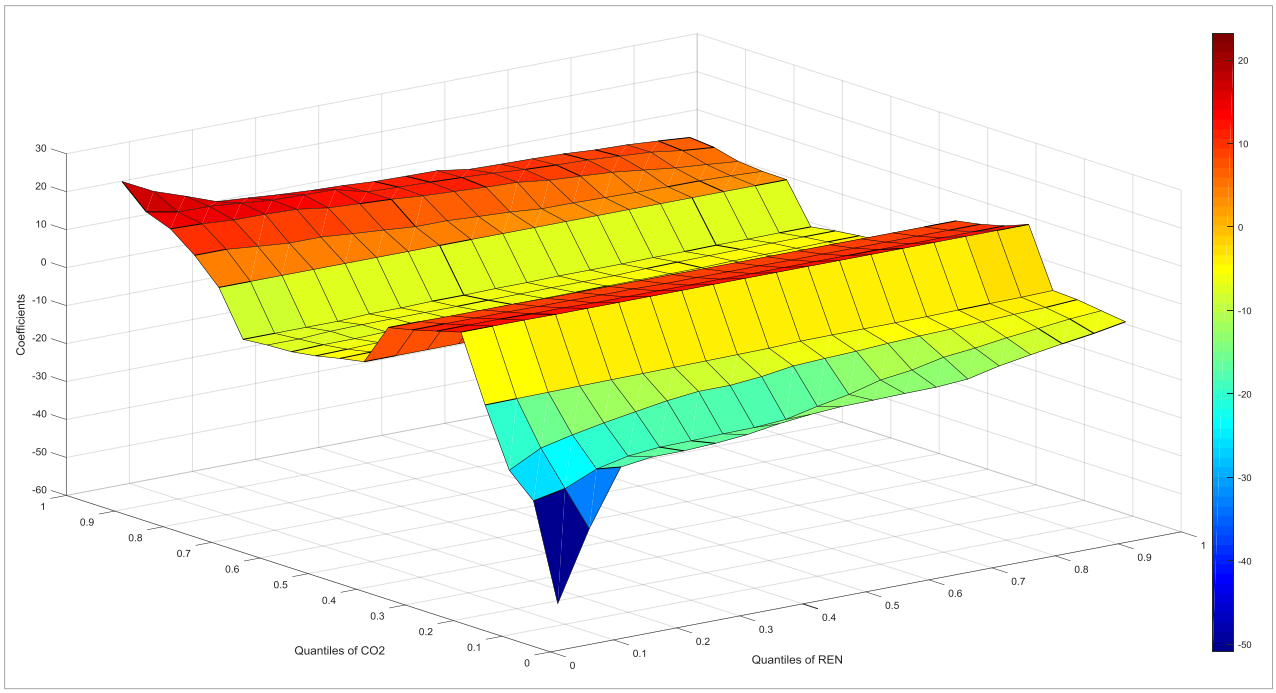

Figure 4d. Impacts of REN on CO_2 emissions

Figure 4a highlights the influence of economic growth on CO_2 emissions in India. The slope coefficient spans between -15 and 20. The negative effect of GDP on CO_2 emissions is found at all quantiles of GDP and lower quantiles of CO_2 (0.15–0.35). In addition, the coefficient of slope is weak and positive in the medium and higher quantiles of CO_2 and different quantiles of GDP. These findings reveal that both positive and negative impacts exist between GDP and CO_2 emissions in India, but they are evidence of a weak relationship. More importantly, the positive nexus is observed throughout the quantiles of GDP and the majority of quantiles of CO_2 emissions, so the GDP is a dramatic driver of India's CO_2 emissions. This result is consistent with previous articles such as Pachiyappan et al. [8], Mehmood et al. [24], and Khochiani & Nademi [7], which indicate that GDP is a considerable factor of CO_2 emissions.

Figure 4b demonstrates the influence of globalization on CO_2 emissions in India. The scale of the slope of coefficients ranges from -25 to 10. In all quantiles of CO_2 and GLO (0.1-0.95), the impact of GLO on CO_2 is significantly negative,

and the negative impact is more pronounced across lower and higher quantiles of CO_2, which implies that an increase in globalization will lower CO_2 emissions. This demonstrates that globalization decreases CO_2 emissions. In addition, this shows the Indian government's empathy and care for reducing CO_2 emissions through the adoption of environmental regulations in tandem with the country's rapid economic expansion. A possible explanation for globalization's negative influence on CO_2 is that its rise in trade declines overall factor productivity because of globalization, and the transition of cutting-edge technologies fuels economic development. These results are not surprising and are in line with the findings of Acheampong [22] for Ghana.

In the pair GRE-CO_2, the outcome examines that the impact of GRE on CO_2 emissions is overall strong negative and significant in the lower and middle quantiles of CO_2 and all quantiles of green growth [see Figure 4c]. Specifically, the influence of GRE on CO_2 emissions is more noteworthy in the lower quantiles of CO_2, indicating the maximum influence of green growth on the environmental quality in India. In other words, the results of QQR affirm that the influence of green growth on CO_2 is strongly negative and significant in almost all quantiles of GRE. Similar findings were studied by previous papers such as Ulucak [4] and Tawiah et al. [6], who suggest that an increase in green growth leads to a decline in CO_2 and energy conservation.

Finally, Figure 4d shows the influence of renewable energy on CO_2 emissions. The findings uncover that in the lower tail (0.1–0.4) quantiles of CO_2, REN influences CO_2 negatively, which means that in the lower quantiles, renewable energy is sustainable. More so, the finding is surprising given the fact that fossil fuel energy utilization is unsustainable in this country. In addition, in the middle quantiles of CO_2 and all quantiles of REN, the impact of REN on CO_2 is negative and strong. Nevertheless, as we move into the higher quantiles of CO_2 (0.85-0.95), all quantiles of REN are positive and weak. This means that in the longer tail, the REN contributes to the environmental degradation in India. The positive influence of REN on CO_2 is revealed by the research of Uzair Ali et al. [15], Kang et al. [34], and Danish and Ulucak [4]. Overall, the findings confirm that the influence of REN on CO_2 is negative and substantial in all quantiles of mixture, which suggests that REN declines the level of CO_2 emission. From a policy viewpoint, the outcomes indicate that policymakers should adopt renewable energy consumption to reduce environmental degradation in India.

The findings reveal that the impact of renewable energy, GDP, green growth, and globalization on CO_2 emissions is statistically significant for all quantiles. In addition, these influences are not symmetrically across different quantiles of examined variables, which mitigates past articles which have reported a statistically significant [24, 25, 31- 34]. Our results complement these studies by showing that only negative shocks to economic development and renewable energy consumption are significant for carbon emissions. Recent debates indicate that, while economically advantageous, industrial progress has had an influence on environmental quality [23, 27]. Increased growth and industrial activity have exacerbated India's already unstable pollution levels. Our work is consistent with analysis of Jayasinghe & Selvanathan [25] on highly decentralized economies.

We employ the spectral Granger causality at different frequencies introduced by Breitung & Candelon [11] to determine the causal impact of REN, GLO, GDP, and GRE on CO_2 emissions in India. At various frequencies (0-1, 1-2, and 2-3), the causal link between CO_2 emissions and regressor indicators suggests long-term, medium-term, and short-term, respectively. Interim relationships are identified as frequencies between 2 and 3, while persistent causality is stated as frequencies from 0 to 1. Figure 4 displays the graphical findings of this test. A 5% level of significance is indicated by the upper line (red), while a 10% level of significance is indicated by the bottom line (blue).

Overall, the test uncovers a permanent dynamic spillover causality in the long run, running from GDP, REN, GRE, and GLO to CO_2 emissions in India. Nevertheless, the outcome indicates that the causality from CO_2 to these independent variables is mixed. For example, in the case of the GLO-CO_2 pair, Figure 5 depicts that there is no significant causal nexus in the direction running from CO_2 to globalization. For the asymmetric nexus between economic growth, green growth, globalization, renewable energy, and carbon emissions, we note a non-significant causality in the short term. In general, there is a two-way causality between GRE, GDP, REN, and CO_2 at low and medium frequencies and a one-way causality running from GLO to CO_2 in the long run, which implies that the causality is evident in medium and long-run horizons. Our results are consistent with past articles that suggest that renewable energy, globalization, and green growth could enhance the environmental quality in India.

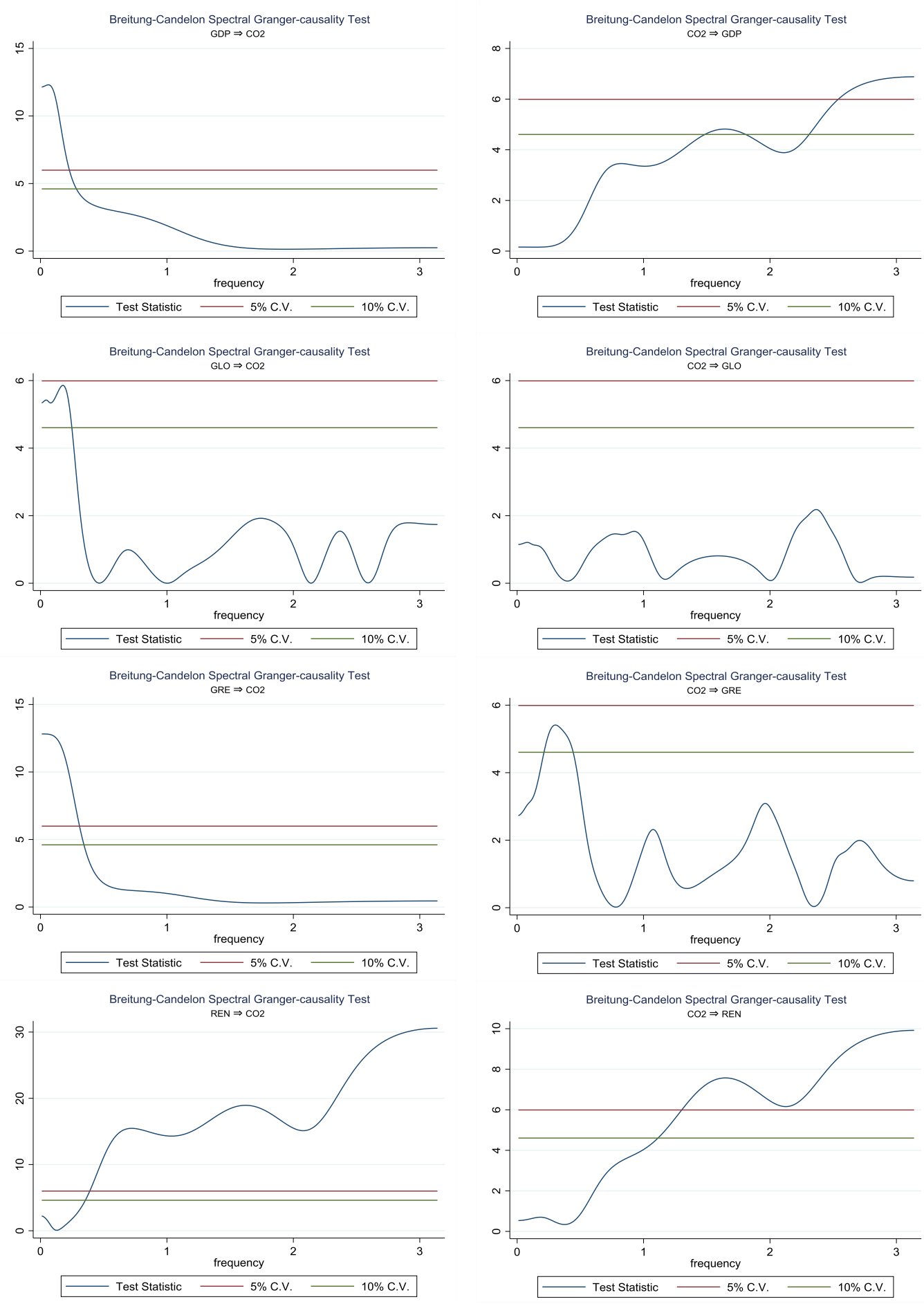

Figure 5. Spectral Granger causality between CO_2 emissions and selected variables

6- Conclusion and Policy Implications

This article explores the asymmetric impacts of economic growth, globalization, green growth, and renewable energy on CO_2 emissions in India from 1990 to 2022. The authors believe that, despite the newly established empirical methodology in this study, the impact of economic expansion, globalization, green growth, and renewable energy consumption on environmental quality in India has not been adequately examined. As a result, by using the innovative and recently established quantile-on-quantile approach to examine the effects of the regressors on CO_2 emissions, our article fills the gap in the literature for the instance of India. Additionally, the causal relationship between the examined variables is assessed employing the spectral Granger causality test.

The empirical results of the QQR model indicate that economic growth has an adverse effect on environmental degradation in the majority of the quantiles. By contrast, the outcomes reveal that globalization mitigates CO_2 emissions, as most quantiles show that GLO's influence on CO_2 emissions is negative. Similar results are disclosed in the cases of green growth, renewable energy, and CO_2 emissions, in which these regressors negatively impact environmental quality in a large proportion of the quantiles. More specifically, the findings of the spectral Granger causality test reveal that economic growth, globalization, green growth, and renewable energy would cause remarkable fluctuations in CO_2 emissions at various time horizons.

These large findings have important policy implications for Indian policymakers, regulatory authorities, and governments. Because globalization has been shown to increase environmental quality, it is vital for this country to green its globalization policies. Specifically, these policies should not only attempt to achieve substantial economic advantages, but they should also preferably work to mitigate the associated environmental problems. Implementing environmental policy tools, such as emissions trading programs and carbon taxes, may continue to be a crucial tool for controlling CO_2 emissions.

It is observed that fluctuations in the growth rate of the gross domestic product have a significant influence on and explanation for the growth rate of CO_2 emissions. Since India's growth is mostly dependent on the use of nonrenewable energy sources, the country's high economic growth rate also leads to an increase in CO_2 emissions. India should keep using its current economic system-strengthening measures since they do not pose a threat to the environment. In addition, India has to establish a stable economic framework that will enable companies to use cutting-edge and effective technology, use less energy, and enhance the environment. This will incentivize companies to use eco-friendly technologies in order to reap financial benefits and reduce their energy consumption and greenhouse gas emissions.

Concerning the negative green growth-CO_2 relationship, it is critical to continue to strengthen India's current economic structure's green transition. In order to properly integrate the goal of lowering carbon emissions into long-term socioeconomic development planning, local governments should strengthen their low-carbon and green development planning, pass pertinent laws and regulations, and integrate green economic development into the design of top-level policies. Importantly, clean energy measures should be prioritized by policymakers in order to improve environmental quality. Improving energy efficiency, investing in renewable resources, increasing the use of cleaner energy sources, and reducing energy intensity are the primary methods for reducing carbon emissions.

7- Declarations

7-1- Data Availability Statement

The data presented in this study are available on request from the corresponding author.

7-2- Funding

This research was funded by Hung Vuong University, Ho Chi Minh City.

7-3- Institutional Review Board Statement

Not applicable.

7-4- Informed Consent Statement

Not applicable.

7-5- Conflicts of Interest

The author declares that there is no conflict of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancies have been completely observed by the author.

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