Globalization and renewable energy use: how are they contributing to upsurge the CO2 emissions? A global perspective

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RESEARCH ARTICLE

Globalization and renewable energy use: how are they contributing to upsurge the CO_2 emissions? A global perspective

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Abstract
The present study major aim was to examine the impact of globalization, economic growth, population growth, renewable energy usage and nuclear energy on CO_2 emissions globally by taking the annual data varies from 1985 to 2020. Stationarity among study variables were tested via unit root testing, while nonlinear autoregressive distributed lag (NARDL) technique was used to demonstrate the linkages among variables with the estimation of long-run and short-run. Study results reveal that both in the short run and long run, negative globalization and economic growth shocks positively and negatively influence CO_2 emissions, respectively. Besides, higher population growth is found to positively influence CO_2 emissions while renewable energy consumption cannot influence the CO_2 emission figures. Lastly, positive and negative shocks to alternative nuclear energy consumption are evidenced to negatively influence CO_2 emissions both in the short run and long run. Hence, in line with these findings, several new policies and strategies are recommended for reducing carbon emissions globally.

Keywords CO_2 emissions · Environmental pollution · Renewable energy · Economic growth · Population growth

Introduction

Energy is essential to long-term economic progress, but modern economic well-being is threatened by factors such as growing energy demand due to global population expansion, which entails fast consumption of energy sources such as coal, natural gas and oil, as well as rising energy prices. Lack of access to energy indicates a failure to reduce poverty and accelerate development, while greenhouse gas emissions from the combustion of fossil fuels are to blame for global warming. As a consequence, continued reliance on this fuel to fulfil rising energy demand will expedite environmental

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degradation (Sebri 2015; Gottschamer and Zhang 2016; Østergaard et al. 2020). During the past quarter century, researchers, ecologists, politicians and economists have focused on environmental pollution and quality issues. Human demand for natural resources has increased environmental concerns such as biodiversity loss, global warming, soil depletion and pollution. Because of unrestricted use of natural resources, the destruction of the biosphere is having a negative impact on the world's long-term economic and social development objectives. A healthy environment is necessary for a thriving economy. Hazardous waste and pollution, as well as resource overexploitation, pose a hazard to economic systems (Figge et al. 2017; Ahmed and Wang 2019; Wang et al. 2022).

Sustainable development and the environment are intertwined. No nation can achieve long-term development without utilizing environmentally friendly energy sources, especially in light of current environmental issues like global warming, pollution, radioactive, waste disposal and ozone depletion as well as the strain on environmental quality caused by economic expansion (Murshed et al. 2021; Cao et al. 2021; Rehman et al. 2021). In addition, there is reduced consumption of resources and it is clear that pollution, energy efficiency and environmental degradation are all linked. Sustainable development is further constrained by the fact that all forms of energy have some effect on the environment to some level. To maximize long-term sustainable growth, a country's ability to cut import costs and protect itself from energy market price volatility is enhanced by a more diverse energy structure, particularly in favour of renewables, as well as increased energy efficiency (Temiz Dinç and Akdoğan 2019; Bilan et al. 2019; Rahman and Velayutham 2020; Destek and Sinha 2020; Gozgor et al. 2018). Since the dawn of time, energy has been the driving force behind economic growth and industrialization. A direct and positive link between economic development and energy use is broadly acknowledged. In recent years, there has been a tremendous change in the global energy industry, and the fuel of the future is becoming more popular as the driving force behind energy production. Though hypotheses have been advanced, there is still a gap in knowledge of how renewable energy contributes to economic growth. Furthermore, the diverse effects of renewable energy production in developed and developing economies have received less attention. Economic growth and renewable energy deployment are inextricably linked, yet most studies focus on either developed and developing economies (Singh et al. 2019; Salim et al. 2014; Behera and Mishra 2020).

The global economy continues to see a rise in carbon emissions, making the Paris Agreement on climate change harder to implement. Understanding the factors that contribute to carbon emissions is critical for developing measures to reduce global warming. Environmental degradation is a persistent and major concern that is rapidly garnering the attention of governments throughout the globe because of its impact on global warming and the potential disruption of the global carbon cycle. Climate change is the most pressing issue confronting mankind today. Climate change caused by greenhouse gas emissions (GHGs), especially CO_2 emission, poses unprecedented threats to growth and human existence, including extreme weather, wildlife extinction and food scarcity (He et al. 2021; Wang et al. 2018). The primary human activity that contributes to CO_2 emission is the use of fossil fuels including coal and natural gas for energy and transportation. However, certain manufacturing activity and land use changes continue to release CO_2 emission. Climate change and global warming might have a variety of negative physiological, physical and ecological effects, including flooding, heat waves, storms and droughts, as well as sea level rise, water system disruption and stunted plant growth. Various investigations have been done to highlight the issues associate renewable energy, urbanization, carbon emission and economic progress. The study of Dong et al. (2020) on renewable energy and carbon emission shows that renewable energy has adversative influence to carbon emission. Kwakwa (2020) investigation on energy consumption in Ghana demonstrated that fossil fuels still accounting for a large portion of the country's overall consumption. Furthermore, Akintande et al. (2020) exploration on renewable energy usage uncover that there is a rise in renewable energy consumption when there is an increase in population growth, urban population, energy demand and electrical power consumption. Similarly, Kwakwa and Alhassan (2018) study show that urbanization and combustible renewables and waste use have a beneficial influence on CO_2 emissions in Ghana, but urbanization and fossil fuel use have a negative effect. On the other side, Sadiq et al. (2022) research on carbon emission, nuclear energy and human development uncover that nuclear energy and financial globalization aid human progress; however, foreign debt hinders it. Although the financial globalization speeds up environmental degradation, nuclear power and foreign debt help to keep things stable. The current study has vital contribution to the existing literature in the consequence of carbon emission contribution to globalization, economic progress, nuclear energy and renewable energy consumption globally. The study used annual data for the analysis and an NARDL technique used to demonstrate the constructive and adversative association among the variables. Furthermore, Fig. 1 illustrates the year-wise global trends of the carbon dioxide emission, globalization index, economic growth, population growth, renewable energy consumption and alternative and nuclear energy consumption.

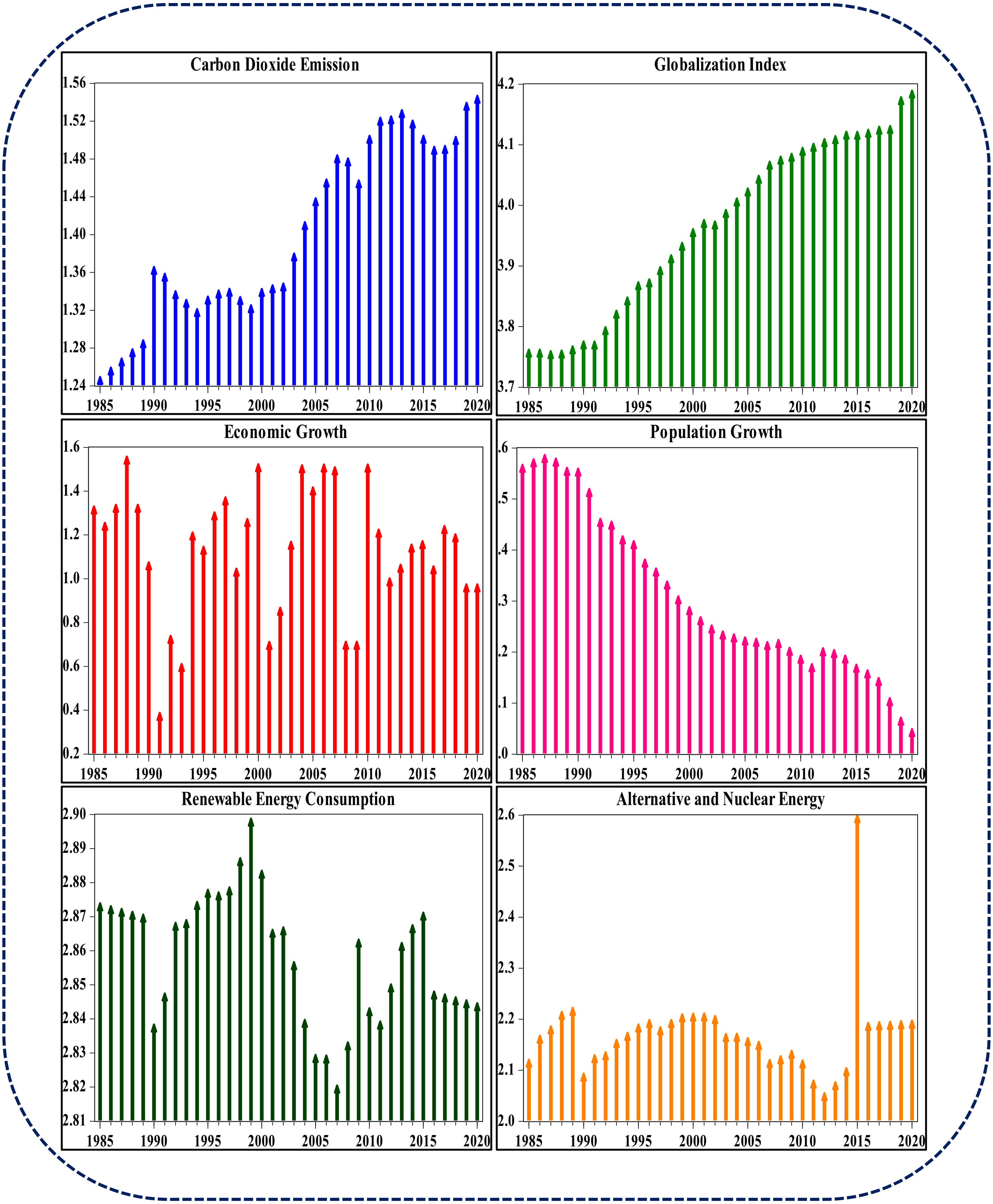

Fig. 1 Global trend of CO_2 emission, globalization index, economic growth, population growth, renewable energy consumption and alternative and nuclear energy

Literature review

Fossil fuel usage has surged as a result of human progress and industrialization. All commercial and non-economic activities in the modern globalized world are strongly dependent on energy inputs. There are concerns about long-term energy security and environmental sustainability because of the high levels of greenhouse gas emissions (GHG). By far, the most urgent environmental challenge that mankind has ever faced is global warming. If this increase is not adequately managed, the environment, economy and human life would suffer tremendously. Human activity causes climate change, and CO_2 emissions are the principal driver of global warming (Ansari et al. 2021; Ahmed et al. 2019). Until common energy from restricted resources is produced, the government should be concerned about its proper use. Growth is considered to be sustainable if it does not put future generations at danger of not being able to meet their own needs due to present population expectations. The three pillars of environmental, economic and social sustainability form the foundation of a long-term economic system. As a result, while assessing sustainable development, it is vital to include both ecological and social impacts. Sustainable economic development demonstrates the solution to coping with natural disasters, weather changes, social and economic difficulties that plague the majority of economies. A key advantage of renewable energy's decentralized structure is that it reduces the impact of a national system failure or an extremist assault by channeling oil revenue to countries with less secure governments (Menegaki and Tiwari 2017; Menegaki and Tugcu 2018; Afonso et al. 2019).

Since the industrial revolution, global manufacturing has grown dramatically. The government should be concerned about the proper use of common energy until it is created from resource constraints. Consumption of fossil fuels has risen considerably as a consequence of increasing worldwide production and a growing global population. Fossil fuel consumption increases in parallel with sustainable economic development, environmental sustainability and public health challenges. In light of the aforementioned tendencies, governments are increasingly turning to renewable energy sources to satisfy their energy demands. It is possible to get carbon-free energy from a variety of renewable resources, such as wind, sun, hydropower, geothermal heat pump steam turbines, biofuels and even the ocean circulation. Countries have moved to renewable energy production despite the fact that it needs substantial expenditure and technology (Manisalidis et al. 2020; Omer 2009; Koohi-Fayegh and Rosen 2020). As the world's population grows, and coal, natural gas and oil are increasingly utilized as energy sources, economic growth declines. As a result, energy prices have risen, pollution has increased and greenhouse gas emissions have expanded, all of which have contributed to global warming. The environmental harm will come as an outcome of reliance on traditional energy sources. Governments worldwide should utilize energy as long as it is accessible. Securing long-term economic development is critical for dealing with the wide range of problems that affect countries across the world, from climate change and natural disasters to economic downturns and social upheavals (Maji et al. 2019; Pfeifer et al. 2018; Gökgöz and Güvercin 2018; Bulut and Muratoglu 2018).

Because of the strong dependence on fossil fuels, there has been concern in several countries over the long-term sustainability of the energy presently being utilized. Alternative energy sources were a hotly debated subject when it came to lowering carbon dioxide emissions and supporting economic development in energy-dependent countries. Governments may be assisted in developing policies that favour sustainable development and their energy sources if they have a thorough grasp of the link between energy usage and CO_2 emissions. In recent years, a number of investigations have sought to examine the relationship between economic development and energy use (Adamu et al. 2020; Song et al. 2018; Zhao et al. 2017). Globalization has an impact on an economy's energy. Density is thought to have a crucial impact. According to the theoretical connection among globalization and energy consumption, the increase and decrease of energy consumption is determined by the combined impacts of numerous fundamental variables, including globalization. Furthermore, the globalization is thought to be connected with improvements in global economic output and income levels, even as trade barriers are reduced, energy consumption tends to rise. As a result of globalization, an economy's energy intensity is anticipated to rise, which is often connected with positive associations in mainstream literature (Shahbaz et al. 2018a; Koengkan 2017; Saud et al. 2018).

As a result of inter- and direct investment, globalization allows countries to flourish collected by fostering their latent and competences and encouraging economic growth. Connectivity between nations was traditionally defined as the development of communications and transportation infrastructure. Globalization has the potential to increase manufacturing regions' competences, capabilities and efficiency and hence contribute to economies of scale. Those that have resources may sell them to countries that do not, which has led to a growth in globalization as a result of the abundance of natural resources. As an importance, globalization and energy efficiency are both boosted by the increased production, investment and foreign exchange facilitated by the usage of natural resources (Balcilar et al. 2017; Hassan et al. 2019; Miao et al. 2017). The long-term viability of economic expansion depends on the availability and use of energy. Oil, coal and natural gas are all nonrenewable sources of energy that contribute to global carbon dioxide emissions and raise the cost of energy over time. Energy shortages is increasing poverty and contributing to climate change in many parts of the globe as a result of increased carbon dioxide emissions caused by rising energy costs. This will have a significant impact on the environment, since global energy production is a major source of pollution owing to the great bulk of such an industry's use of fossil fuels. It is critical to realize that global sources of fossil fuels are finite. As the need for energy develops, humans are always looking for new energy sources that can be provided without putting excessive burden on the Earth's environment. Renewable energy is far less expensive than traditional fossil fuel energy sources, which is a significant advantage of renewable energy. People's overall standard of life will rise as a consequence of long-term cost savings through the use of alternative or green energy sources (Lin and Agyeman 2019; Menegaki 2011; Li et al. 2021).

Energy from renewable sources is less costly in economies where it is reasonably easy to expand. The amount of primary energy used is determined by projections of future technological and economic progress. The capacity to create energy is critical to the economy's development and future. Energy is the only resource that can meet the needs of national development. A country's energy sector must be in excellent shape if it is to remain competitive and economically stable in the future (Przychodzen and Przychodzen 2020; Soava et al. 2018; Widiyanti et al. 2019). Energy is also a significant aspect in accomplishing economic development objectives. Using renewable energy has a substantial influence on reducing CO_2 emissions, as shown by research studies. Demand for renewable energy has gradually increased in recent years, and this trend is projected to continue in the near future. Growth in the population has been linked to a rise in energy consumption, which in turn has led to an increase in the energy sector's capacity. Estimates like these show that the world's energy consumption has raised as a consequence of an increased reliance on fossil fuels. Because of the increasing demand for fossil fuels, carbon emissions into the atmosphere have grown, contributing to environmental degradation and climate change. Energy consumption reduces greenhouse gas emissions, but the use of unpolluted energy has not surpassed stipulated limits to minimize carbon dioxide production, while the creation of renewable energy lowers the danger of environmental harm, so it may be generated from fossil fuel resources. It is challenging to make the switch to more environmentally friendly energy use (Menyah and Wolde-Rufael 2010; Ahmad and Zhao 2018; Hanif 2018; Acheampong 2018).

Data and methods

We have used time sequence data in this investigation to show the association among the variables and range is 1985–2020. The sources of this data are World Development Indicators and KOF Globalization Index. The key variables used in this examination include the CO_2 emission, globalization index, economic growth, population growth, renewable energy consumption and alternative and nuclear energy. Table 1 is demonstrating the details of the variables used in this analysis with web links.

Model for the variables

Several studies have been undertaken to show the link between carbon dioxide emissions, foreign direct investment, economic growth, energy consumption, information and communication technology, energy intensity and tourism (Iqbal et al. 2022; Kirikkaleli et al. 2022; Llanos et al. 2022; Bildirici et al. 2022; Rahman et al. 2022). However, in this investigation, we estimated the following model in direction to examine the relationship between CO_2 emissions, globalization, economic growth, population growth, renewable energy consumption and alternative nuclear energy consumption as follows:

$$CO2e_t = f\left(GBI_t, ECG_t, POG_t, REC_t, ANE_t\right) \tag{1}$$

Table 1 Details of the study variables

Study variables	Short form	Data sources	Web. links
CO_2 emission	*CO2e*	WDI	1. https://data.worldbank.org/
Globalization index	*GBI*	KOF Globalization Index	2. https://kof.ethz.ch/en/forecasts-and-indicators/indicators/kof-globalisation-index.html
Economic growth	*ECG*	WDI	
Population growth	*POG*	WDI	
Renewable energy consumption	*REC*	WDI	
Alternative and nuclear energy	*ANE*	WDI	

For more extension, the Eq. (1) can be stated as:

$$CO2e_t = \pi_0 + \pi_1 GBI_t + \pi_2 ECG_t + \pi_3 POG_t + \pi_4 REC_t + \pi_5 ANE_t + \varepsilon_t \tag{2}$$

where Eq. (2) displays that $CO2e_t$ shows carbon dioxide emissions, GBI_t specifies the globalization index, ECG_t exposes the economic growth, POG_t expresses the population growth, REC_t shows the renewable energy consumption and ANE_t stipulate the alternative nuclear energy. In the equation, t is calculating the time duration and π_1–π_5 expose the model coefficients.

The long-run and short-run linkages amid variables can be exposed by utilizing the method of Pesaran et al. (2001) known as autoregressive distributed lag (ARDL) technique. The specification of ARDL model can be expressed as in directive to demonstrate the association among variables as follows:

$$\begin{aligned}\Delta \mathrm{CO2e_t} = \theta_0 &+ \sum_{e=1}^{l} \tau_e \Delta \mathrm{CO2e_{t-e}} + \sum_{e=0}^{l} \beta_e \Delta \mathrm{GBI_{t-e}} + \sum_{e=0}^{l} \vartheta_e \Delta \mathrm{ECG_{t-e}} + \sum_{e=0}^{l} \psi_e \Delta \mathrm{POG_{t-e}} \\ &+ \sum_{e=0}^{l} \pi_e \Delta \mathrm{REC_{t-e}} + \sum_{e=0}^{l} \varphi_e \Delta \mathrm{ANE_{t-e}} + \tau_1 \mathrm{CO2e_{t-1}} + \tau_2 \mathrm{GBI_{t-1}} + \tau_3 \mathrm{ECG_{t-1}} \\ &+ \tau_4 \mathrm{POG_{t-1}} + \tau_5 \mathrm{REC_{t-1}} + \tau_6 \mathrm{ANE_{t-1}} + \varepsilon_t\end{aligned} \tag{3}$$

Equation (3) provides the dynamic link for the specified variables when using this approach.

NARDL model

As a consequence, it is more suited than most standard helpful approaches for particular essential parameters in small samples and has a motivating impact on the participants. The F-test, on the other hand, according to Pesaran et al. (2001), may be used to validate long-term predictions provided particular effects of long-term parameter combinations are assumed. Once cointegration has been established, τ_2–τ_6 calculate the long-term elasticity which is then regularized by τ_1 when it has been established.

By following the study of Shin et al. (2014), the asymmetric technique can be established by decomposing the variables globalization index, economic growth, population growth, renewable energy consumption and nuclear energy with positive ($GBI^+{}_w$;$ECG^+{}_w$;$POG^+{}_w$;$REC^+{}_w$;$ANE^+{}_w$) and negative ($GBI^-{}_w$;$ECG^-{}_w$;$POG^-{}_w$;$REC^-{}_w$;$ANE^-{}_w$) mechanisms and can be stated as follows:

$$GBI^+{}_w = \sum_{w=1}^{w} \Delta GBI^+{}_w = \sum_{w=1}^{w} \max\left(\Delta GBI^+{}_w, 0\right) \tag{4}$$

$$GBI^-{}_w = \sum_{w=1}^{w} \Delta GBI^-{}_w = \sum_{w=1}^{w} \min\left(\Delta GBI^-{}_w, 0\right) \tag{5}$$

$$ECG^+{}_w = \sum_{w=1}^{w} \Delta ECG^+{}_w = \sum_{w=1}^{w} \max\left(\Delta ECG^+{}_w, 0\right) \tag{6}$$

$$ECG^-{}_w = \sum_{w=1}^{w} \Delta ECG^-{}_w = \sum_{w=1}^{w} \min\left(\Delta ECG^-{}_w, 0\right) \tag{7}$$

$$POG^+{}_w = \sum_{w=1}^{w} \Delta POG^+{}_c = \sum_{w=1}^{w} \max\left(\Delta POG^+{}_w, 0\right) \tag{8}$$

$$POG^-{}_w = \sum_{w=1}^{w} \Delta POG^-{}_w = \sum_{w=1}^{w} \min\left(\Delta POG^-{}_w, 0\right) \tag{9}$$

$$REG^+{}_w = \sum_{w=1}^{w} \Delta REG^+{}_w = \sum_{w=1}^{w} \max\left(\Delta REG^+{}_w, 0\right) \tag{10}$$

$$REG^-{}_w = \sum_{w=1}^{w} \Delta REG^-{}_w = \sum_{w=1}^{w} \min\left(\Delta REG^-{}_w, 0\right) \tag{11}$$

$$ANE^+{}_w = \sum_{w=1}^{w} \Delta ANE^+{}_w = \sum_{w=1}^{w} \max\left(\Delta ANE^+{}_w, 0\right) \tag{12}$$

$$ANE^-{}_w = \sum_{w=1}^{w} \Delta ANE^-{}_w = \sum_{w=1}^{w} \min\left(\Delta ANE^-{}_w, 0\right) \tag{13}$$

The exploration of constructive and adverse shocks for the variables can be exposed by following the Eqs. (4)–(13). Thus, the asymmetrical (NARDL) presentation of the model can be stated as follows:

$$\begin{aligned}\Delta CO2e_t = \beta_0 &+ \sum_{n=1}^{H} \theta_n \Delta CO2e_{t-n} + \sum_{n=0}^{H} \tau_n \Delta GBI^+{}_{t-n} \\ &+ \sum_{n=0}^{H} \omega_n \Delta GBI^-{}_{t-n} + \sum_{n=0}^{H} \alpha_n \Delta ECG^+{}_{t-n} \\ &+ \sum_{n=0}^{H} \varphi_n \Delta ECG^-{}_{t-n} + \sum_{n=0}^{H} \psi_n \Delta POG^+{}_{t-n} \\ &+ \sum_{n=0}^{H} \gamma_n \Delta POG^-{}_{t-n} + \sum_{n=0}^{H} \vartheta_n \Delta REC^+{}_{t-n} \\ &+ \sum_{n=0}^{H} \rho_n \Delta REC^-{}_{t-n} + \sum_{n=0}^{H} \psi_n \Delta ANE^+{}_{t-n} \\ &+ \sum_{n=0}^{H} \zeta_n \Delta ANE^-{}_{t-n} + \tau_1 CO2e_{t-1} \\ &+ \tau_2 GBI^+{}_{t-1} + \tau_3 GBI^-{}_{t-1} + \tau_4 ECG^+{}_{t-1} \\ &+ \tau_5 ECG^-{}_{t-1} + \tau_6 POG^+{}_{t-1} \\ &+ \tau_7 POG^-{}_{t-1} + \tau_8 REC^+{}_{t-1} + \tau_9 REC^-{}_{t-1} + \tau_{10} ANE^+{}_{t-1} \\ &+ \tau_{11} ANE^-{}_{t-1} + \varepsilon_t\end{aligned} \tag{14}$$

Equation (14) explores the asymmetrical (NARDL) representation for the variables. The exploration of error correction model can be stated as follows:

$$
\begin{aligned}
\Delta CO2e_t = \beta_0 &+ \sum_{n=1}^{H} \theta_n \Delta CO2e_{t-n} + \sum_{n=0}^{H} \tau_n \Delta GBI^{+}{}_{t-n} + \sum_{n=0}^{H} \omega_n \Delta GBI^{-}{}_{t-n} \\
&+ \sum_{n=0}^{H} \alpha_n \Delta ECG^{+}{}_{t-n} + \sum_{n=0}^{H} \varphi_n \Delta ECG^{-}{}_{t-n} + \sum_{n=0}^{H} \psi_n \Delta POG^{+}{}_{t-n} \\
&+ \sum_{n=0}^{H} \gamma_n \Delta POG^{-}{}_{t-n} + \sum_{n=0}^{H} \vartheta_n \Delta REC^{+}{}_{t-n} + \sum_{n=0}^{H} \rho_n \Delta REC^{-}{}_{t-n} \\
&+ \sum_{n=0}^{H} \psi_n \Delta ANE^{+}{}_{t-n} + \sum_{n=0}^{H} \zeta_n \Delta ANE^{-}{}_{t-n} + \tau_1 CO2e_{t-1} + \tau_2 GBI^{+}{}_{t-1} \\
&+ \tau_3 GBI^{-}{}_{t-1} + \tau_4 ECG^{+}{}_{t-1} + \tau_5 ECG^{-}{}_{t-1} + \tau_6 POG^{+}{}_{t-1} + \tau_7 POG^{-}{}_{t-1} \\
&+ \tau_8 REC^{+}{}_{t-1} + \tau_9 REC^{-}{}_{t-1} + \tau_{10} ANE^{+}{}_{t-1} + \tau_{11} ANE^{-}{}_{t-1} + \theta ECM_{t-1} + \varepsilon_t
\end{aligned} \tag{15}
$$

Equation (15) exhibits the exploration of error correction model.

Outcomes and discussion

Descriptive and correlation technique

Tables 2 and 3 demonstrate the effects of summary statistics and correlations. In addition, all variables were found to be identical. There were no semi-distribution concerns based on the statistical significance of the Jarque–Bera statistic for the multiple research variables. A high association between the responding variable and the explanatory variable was also found by doing a pairwise correlation investigation. When a model variable integrates across levels or at the first difference, or a combination of the two, then NARDL analysis may be used; however, when a model variable integrates at the second difference, then NARDL analysis cannot be used. As a result, we will run some numbers to figure out where the real problems lie.

Stationarity test among variables

This study used the unit root tests to monitor variables that are in a stable phase. Table 4 displays the results of the unit root testing. Three-unit root techniques including the Dickey Fuller (DF-GLS), Phillips-Perron (PP) and KPSS were used to examine the order of integration for every variable (Fuller 1979; Phillips and Perron 1988; Kwiatkowski et al. 1992). Variables' test statistics and probability values demonstrate a series' stationary tendency. A one-step order of integration modification causes the model's variables to go from being non-stationary to stationary. It is assumed that the variables are stationary and cannot be removed sequentially according to the stationarity measure, which is the null hypothesis.

Bounds testing with cointegration

This analysis utilized the NARDL technique to encounter the linkages amid the study variables including carbon emission, economic growth, renewable energy, alternative and nuclear energy and population growth. The AIC (Akaike information criterion) in the instruction to complete the bounds test to the cointegration assessment requires that the F-statistic can be calculated in an adequate period of time. As can observe in Table 5, the F-statistic (4.179) estimates are statistically significant.

Furthermore, this study also utilized the cointegration technique of Johansen and Juselius with critical values at

Table 2 Outcomes of summary analysis

	Mean	Median	Max	Mini	Std. Dev	Skewness	Kurtosis	Jarque–Bera	Probability
CO2e	1.400	1.368	1.542	1.245	0.093	0.041	1.564	3.103	0.211
GBI	3.965	3.977	4.182	3.752	0.143	−0.220	1.613	3.173	0.204
ECG	1.126	1.168	1.539	0.369	0.290	−0.643	2.859	2.517	0.284
POG	0.302	0.238	0.578	0.041	0.159	0.457	2.002	2.750	0.252
REC	2.858	2.863	2.897	2.819	0.018	−0.154	2.231	1.030	0.597
ANE	2.166	2.164	2.591	2.047	0.085	3.384	18.506	4.380	0.000

Table 3 Analysis of correlation

	CO2e	*GBI*	*ECG*	*POG*	*REC*	*ANE*
CO2e	1.000	0.935	−0.073	−0.880	−0.631	−0.059
GBI	0.935	1.000	0.003	−0.980	−0.486	0.056
ECG	−0.073	0.003	1.000	0.017	−0.018	0.097
POG	−0.880	−0.980	0.017	1.000	0.441	−0.084
REC	−0.631	−0.486	−0.018	0.441	1.000	0.311
ANE	−0.059	0.056	0.097	−0.084	0.311	1.000

Table 4 Unit root test results

	CO2e	*GBI*	*ECG*	*POG*	*REC*	*ANE*
[DF-GLS tests (at the level)]						
Test statistics and *P*-values	0.222 (0.825)	0.089 (0.929)	−3.975 (0.000)	0.167 (0.868)	−1.910 (0.064)	−4.939 (0.000)
[At the first difference]						
Test statistics and *P*-values	−4.956 (0.000)	−4.098 (0.000)	−5.853 (0.000)	−3.525 (0.001)	−5.406 (0.000)	−8.826 (0.000)
[*P-P* test (at the level)]						
Test statistics and *P*-values	−0.863 (0.787)	−0.122 (0.939)	−3.746 (0.007)	−0.321 (0.911)	−2.022 (0.051)	−5.074 (0.000)
[At the first difference]						
Test statistics and *P*-values	−4.855 (0.000)	−4.592 (0.000)	−14.237 (0.000)	−4.276 (0.001)	−5.303 (0.000)	−8.993 (0.000)
[KPSS test (at the level)]						
Test statistics and *P*-values	0.681 (0.000)	0.696 (0.000)	0.054 (0.000)	0.683 (0.000)	0.328 (0.000)	0.085 (0.000)
[At the first difference]						
Test statistics and *P*-values	0.060 (0.018)	0.116 (0.000)	0.471 (0.000)	0.108 (0.000)	0.060 (0.692)	0.500 (0.910)

the level of 5% (Johansen and Juselius 1990), and outcomes are presented in Table 6.

NARDL technique outcomes

The NARDL technique outcomes are displayed in Table 7 with the estimation of long and short runs.

Firstly, the short-run outcomes reveal that only negative shocks to the globalization index influence carbon emissions. Since the predicted coefficient is negative, it implies that as the level of globalization declines, the carbon emission levels tend to go up. Similarly, in the context of economic growth, it can be seen that only in the case of negative economic growth shocks, the carbon emission levels are negatively influenced. Besides, it is also observed that higher population growth is positively linked with CO_2 emissions; this finding is in line with the understanding that higher population induces higher energy demand and, therefore, triggers higher emissions of carbon. On the other hand, a positive shift in renewable energy consumption reduces carbon emissions. Regarding the use of nuclear energy, it is evident that negative and positive shocks to nuclear energy negatively influence CO_2 emissions.

Table 5 Outcomes of bounds testing

(*F*-bounds test)		Null hypo. that found no level relationship		
T-statistic	Value	Significance level	*I*(0)	*I*(1)
F-stat. value	4.179	[10%]	{1.76}	{2.77}
K	10	[5%]	{1.98}	{3.04}
		[2.5%]	{2.18}	{3.28}
		[1%]	{2.41}	{3.61}

Secondly, the long-run outcomes portray that negative globalization shocks positively influence CO_2 emissions which corroborates the corresponding short-run scenario. Likewise, negative economic growth shock is found to decline CO_2 emissions which, much like the short-run scenario, indicates that slowing down economic activities can result in lower use of energy whereby the carbon emission levels are likely to go down. Furthermore, positive and negative shocks to population growth rate are also evidenced to stimulate higher carbon emissions while renewable energy consumption is once again found to be ineffective in influencing CO_2 emissions. Lastly, regarding the use of nuclear energy, it can be seen

Table 6 J-cointegration test

Hypo-No. of CE(s)	*E*-values	*T*-statistics	*C*-values (0.05)	Prob. values**
Unrestricted cointegration rank test (trace)				
None*	0.675	107.795	95.753	0.005
At most 1	0.646	69.492	69.818	0.053
At most 2	0.375	34.153	47.856	0.493
At most 3	0.308	18.158	29.797	0.554
At most 4	0.139	5.620	15.494	0.739
At most 5	0.015	0.521	3.841	0.470
Unrestricted cointegration rank test (maximum eigenvalue)				
None	0.675	38.303	40.077	0.078
At most 1*	0.646	35.338	33.876	0.033
At most 2	0.375	15.995	27.584	0.666
At most 3	0.308	12.537	21.131	0.495
At most 4	0.139	5.098	14.264	0.729
At most 5	0.015	0.521	3.841	0.470

* shows the denial at 0.05 level; ** indicates the probability values

Table 7 Long-run and short-run analyses

Variables	Coefficients	S-error	*t*-statistic	Prob
Short-run outcomes				
C	0.462	0.264	1.750	0.101
CO2(− 1)	− 0.363	0.198	− 1.835	0.087
GBI_POS(− 1)	0.722	0.233	3.090	0.008
GBI_NEG	− 4.728	8.864	− 0.533	0.602
ECG_POS(− 1)	0.028	0.018	1.537	0.146
ECG_NEG(− 1)	− 0.048	0.034	− 1.436	0.172
POG_POS	0.172	0.364	0.472	0.643
POG_NEG(− 1)	0.589	0.209	2.816	0.013
REC_POS(− 1)	− 1.301	0.648	− 2.006	0.064
REC_NEG(− 1)	1.039	0.698	1.487	0.159
ANE_POS(− 1)	− 0.267	0.100	− 2.651	0.019
ANE_NEG(− 1)	− 0.414	0.118	− 3.497	0.003
D(GBI_POS)	0.950	0.269	3.526	0.003
D(ECG_POS)	− 0.000	0.015	− 0.025	0.980
D(ECG_NEG)	− 0.006	0.014	− 0.458	0.653
D(POG_NEG)	− 0.165	0.197	− 0.837	0.416
D(REC_POS)	− 2.235	0.722	− 3.094	0.007
CointEq(− 1)	− 0.363	0.038	− 9.463	0.000
Long-run outcomes				
GBI_POS	1.987	1.047	1.896	0.078
GBI_NEG	− 13.002	29.006	− 0.448	0.660
ECG_POS	0.077	0.074	1.043	0.314
ECG_NEG	− 0.134	0.116	− 1.156	0.266
POG_POS	0.474	0.949	0.499	0.625
POG_NEG	1.621	1.061	1.526	0.149
REC_POS	− 3.578	2.305	− 1.552	0.142
REC_NEG	2.857	3.142	0.909	0.378
ANE_POS	− 0.736	0.363	− 2.024	0.062
ANE_NEG	− 1.139	0.623	− 1.827	0.089
C	1.270	0.052	24.039	0.000
[R-squared (0.996)]		[Mean dependent var (1.409)]		
[Adjusted R-squared (0.990)]		[S.D. dependent var (0.088)]		
[S.E. of regression (0.008)]		[Akaike info criterion (− 6.401)]		
[Sum squared resid (0.001)]		[Schwarz criterion (− 5.503)]		
[Log likelihood (128.829)]		[Hannan-Quinn criter. (− 6.095)]		
[Durbin-Watson stat (2.239)]				

that positive and negative shocks to alternative nuclear energy reduce the CO_2 emissions; similar scenario in the short-run was evidenced earlier.

In light of these findings, it can be said that globalization is a phenomenon in which countries consolidate via inter- and direct investments, allowing countries to benefit together through the development of their potential and capabilities, as well as the economic support of growth. There was a period when the term meant building communication and transportation infrastructure to connect disparate regions, but the concept has since broadened. Through more trade across borders, globalization has the ability to strengthen manufacturing countries' capabilities, competencies and efficiency. This might be a major component in reaching economies of scale. Natural resource richness has also aided globalization, since countries with resources may convert them into a useable form that can be supplied to those lacking them. Natural resource exploitation results in increased trade, investment and currency exchange, all of which lead to greater globalization and improved energy efficiency (Latif et al. 2018; Atil et al. 2020; Kwakwa et al. 2020). Globalization has an impact on environmental quality via the income effect, the technology effect and the composition effect. The income effect shows that although globalization increases the quantity of output and industry in an economy, economic development reduces environmental quality through increasing carbon emissions. The technological effect demonstrates that as a result of globalization, countries now have better access to energy-efficient technologies. Utilize energy-saving technologies to improve environmental quality by lowering carbon emissions. Composition effects demonstrate that globalization affects the capital-labour ratio, hence influencing the economy's structure (Shahbaz et al. 2018b; Rahman and Kashem 2017).

Because of their dependence on cheap and plentiful nonrenewable energy sources, environmental degradation will intensify in emerging economies. These economies are hesitant to abandon nonrenewable energy sources since it is more beneficial to reduce poverty, food insecurity and economic advancement to do so. Furthermore, in the pursuit of economic progress, low-income countries have ignored the long-term repercussions of fossil fuel consumption, polluting the environment with poisonous gases (Hanif 2018; Pourreza et al. 2018). Economic growth in the developing world is a major issue in creating environmental goals, and rising energy consumption poses a severe threat to ecological sustainability due to its negative impact on environmental quality. Furthermore, structural factors such as shifting demographics, quicker economic growth in emerging and developing countries and an increase in industrialization, electrification and transportation will all contribute to an increase in energy consumption (Danish 2019; Baloch et al. 2019). Carbon dioxide and other greenhouse gas emissions may be decreased largely by using renewable energy sources. Governments, on the other hand, have significant difficulties in adopting renewable energy policy due to the high costs of integrating new technologies. To combat environmental degradation, the sector's technologies are seen to be critical in the use of renewable energy. Pollution is caused by the usage of natural resources, with CO_2 emissions being the most notable contaminant. Both humans and industrial processes contribute to the accumulation of emissions in the atmosphere. In addition to fossil fuels, natural gas is an important source of business and residential power generation. Heat and temperature rise as a consequence of emissions that coat the atmosphere to prevent gases from escaping. The on-going rise of the petroleum business, which is inextricably tied to human existence, has had a detrimental influence on environmental evaluations of fossil fuel and petroleum wastewater treatment (Zhang et al. 2019; Aydin and Turan 2020; Sahoo and Sahoo 2022; Zafar et al. 2022). Table 8 presents the results of the stability and diagnostic tests with F-statistic values (0.980, 1.045) and probability values (0.403, 0.474).

Table 8 Stability and diagnostic test outcomes

Tests	F-statistics	Prob.-values
[Breusch-Godfrey serial correlation LM test]	0.980	0.403
[Heteroskedasticity test (Breusch-Pagan-Godfrey)]	1.045	0.474
[CUSUM test]		Stable
[CUSUM of squares test]		Stable

Furthermore, cumulative and its sum of squares are plotted in Fig. 2 at the level of 5% significance.

The multiplier impacts of globalization index, economic growth, renewable energy consumption, population growth and alternative and nuclear energy with having positive and negative shocks are presented in Fig. 3.

Conclusion and recommendations

The impact of globalization, economic growth, population growth, renewable energy consumption and alternative and nuclear energy on CO_2 emissions was determined in this analysis by taking the annual data from 1985 to 2020. A nonlinear autoregressive distributed lag method was used to uncover the association among variables. Study results show that both in the short run and long run, negative globalization and economic growth shocks positively and negatively influence the CO_2 emissions. Besides, higher population growth is found to positively influence CO_2 emissions while renewable energy consumption cannot influence the carbon emission. Lastly, positive and negative shocks to alternative nuclear energy consumption are evidenced to negatively influence carbon emissions both in the short-run and long-run dynamics.

New solid initiatives and strategies are necessary internationally to decrease the CO_2 emissions in order to avert environmental degradation. Globalization is occurring in both developing and industrialized economies, and this tendency has unforeseen environmental repercussions. Countries were more industrialized and increased production to satisfy expanding demand. These activities, in turn, emit a variety of greenhouse gases that contribute significantly to global warming. Human actions are most likely to blame for global warming, which has everyone worried and elevated it to the rank of a global crisis. The uniform structure of the atmosphere is being affected by greenhouse gas emissions from various activities such

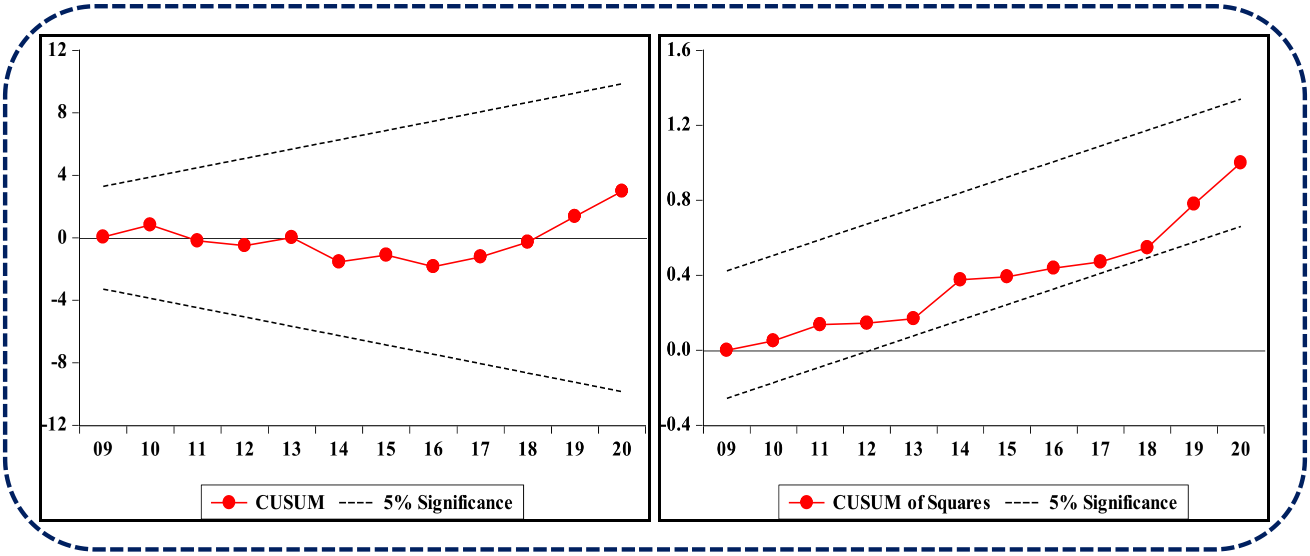

Fig. 2 Plot of CUSUM and its square

as industry, transportation, agriculture and consumer behaviour. The biggest problem damaging the environment and contributing to climate change is increased pollution from a variety of sources. As a result of globalization, increased global competition has resulted in increased goods production and the emission of massive amounts of hazardous gases. Prior to globalization, carbon dioxide emissions remained an environmental issue, independent of global warming. In order to reduce carbon emissions, innovative technologies that may enhance process output while lowering pollutants worldwide are required. Continuous resource exploitation and environmental neglect have permanently altered the ecosystem, causing environmental damage that leads to climate change.

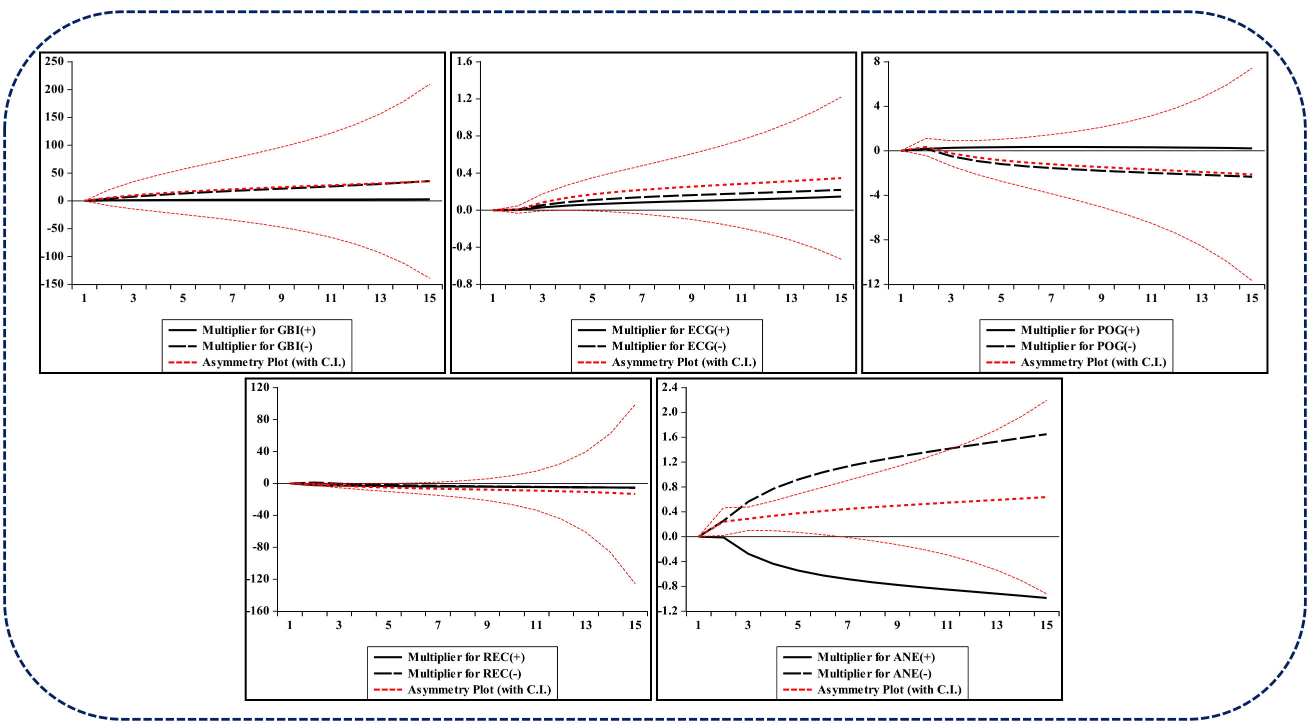

Fig. 3 Multiplier impacts of GBI, ECG, POG, REC and ANE

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References

Acheampong AO (2018) Economic growth, CO2 emissions and energy consumption: what causes what and where? Energy Econ 74:677–692

Adamu MB, Adamu H, Ade SM, Akeh GI (2020) Household energy consumption in Nigeria: a review on the applicability of the energy ladder model. J Appl Sci Environ Manag 24(2):237–244

Afonso TL, Marques AC, Fuinhas JA (2019) Energy–growth nexus and economic development: a quantile regression for panel data. In The extended energy-growth nexus, Academic Press, pp. 1–25. https://doi.org/10.1016/B978-0-12-815719-0.00001-2

Ahmad M, Zhao ZY (2018) Empirics on linkages among industrialization, urbanization, energy consumption, CO2 emissions and economic growth: a heterogeneous panel study of China. Environ Sci Pollut Res 25(30):30617–30632

Ahmed Z, Wang Z (2019) Investigating the impact of human capital on the ecological footprint in India: an empirical analysis. Environ Sci Pollut Res 26(26):26782–26796

Ahmed Z, Wang Z, Mahmood F, Hafeez M, Ali N (2019) Does globalization increase the ecological footprint? Empirical evidence from Malaysia. Environ Sci Pollut Res 26(18):18565–18582

Akintande OJ, Olubusoye OE, Adenikinju AF, Olanrewaju BT (2020) Modeling the determinants of renewable energy consumption: evidence from the five most populous nations in Africa. Energy 206:117992

Ansari MA, Haider S, Masood T (2021) Do renewable energy and globalization enhance ecological footprint: an analysis of top renewable energy countries? Environ Sci Pollut Res 28(6):6719–6732

Atil A, Nawaz K, Lahiani A, Roubaud D (2020) Are natural resources a blessing or a curse for financial development in Pakistan? The importance of oil prices, economic growth and economic globalization. Resour Policy 67:101683

Aydin M, Turan YE (2020) The influence of financial openness, trade openness, and energy intensity on ecological footprint: revisiting the environmental Kuznets curve hypothesis for BRICS countries. Environ Sci Pollut Res 27(34):43233–43245

Balcilar M, Bekiros S, Gupta R (2017) The role of news-based uncertainty indices in predicting oil markets: a hybrid nonparametric quantile causality method. Empir Econ 53(3):879–889

Baloch MA, Mahmood N, Zhang JW (2019) Effect of natural resources, renewable energy and economic development on CO2 emissions in BRICS countries. Sci Total Environ 678:632–638

Behera J, Mishra AK (2020) Renewable and non-renewable energy consumption and economic growth in G7 countries: evidence from panel autoregressive distributed lag (P-ARDL) model. IEEP 17(1):241–258

Bilan Y, Streimikiene D, Vasylieva T, Lyulyov O, Pimonenko T, Pavlyk A (2019) Linking between renewable energy, CO2 emissions, and economic growth: challenges for candidates and potential candidates for the EU membership. Sustainability 11(6):1528

Bildirici ME, Castanho RA, Kayıkçı F, Genç SY (2022) ICT, energy intensity, and CO2 emission nexus. Energies 15(13):4567

Bulut U, Muratoglu G (2018) Renewable energy in Turkey: great potential, low but increasing utilization, and an empirical analysis on renewable energy-growth nexus. Energy Policy 123:240–250

Cao H, Khan MK, Rehman A, Dagar V, Oryani B, Tanveer A (2021) Impact of globalization, institutional quality, economic growth, electricity and renewable energy consumption on carbon dioxide emission in OECD countries. Environ Sci Pollut Res 1-12. https://doi.org/10.1007/s11356-021-17076-3

Danish WZ (2019) Investigation of the ecological footprint's driving factors: what we learn from the experience of emerging economies. Sustain Cities Soc 49:101626

Destek MA, Sinha A (2020) Renewable, non-renewable energy consumption, economic growth, trade openness and ecological footprint: evidence from organisation for economic Co-operation and development countries. J Clean Prod 242:118537

Dogan E, Turkekul B (2016) CO2 emissions, real output, energy consumption, trade, urbanization and financial development: testing the EKC hypothesis for the USA. Environ Sci Pollut Res 23(2):1203–1213

Dong K, Dong X, Jiang Q (2020) How renewable energy consumption lower global CO2 emissions? Evidence from countries with different income levels. World Econ 43(6):1665–1698

Espa I, Holzer K (2018) Negotiating 21st century rules on energy: what is at stake for the European Union, the United States and the BRICS? J World Invest Trade 19(3):415–443

Figge L, Oebels K, Offermans A (2017) The effects of globalization on ecological footprints: an empirical analysis. Environ Dev Sustain 19(3):863–876

Fuller WA (1979) Distribution of the estimators for autoregressive time series with a unit root. J Am Stat Assoc 74(366a):427–431

Gökgöz F, Güvercin MT (2018) Energy security and renewable energy efficiency in EU. Renew Sustain Energy Rev 96:226–239

Gottschamer L, Zhang Q (2016) Interactions of factors impacting implementation and sustainability of renewable energy sourced electricity. Renew Sustain Energy Rev 65:164–174

Gozgor G, Lau CKM, Lu Z (2018) Energy consumption and economic growth: new evidence from the OECD countries. Energy 153:27–34

Hanif I (2018) Impact of economic growth, nonrenewable and renewable energy consumption, and urbanization on carbon emissions in sub-Saharan Africa. Environ Sci Pollut Res 25(15):15057–15067

Hanif I, Gago-de-Santos P (2017) The importance of population control and macroeconomic stability to reducing environmental degradation: an empirical test of the environmental Kuznets curve for developing countries. Environ Dev 23:1–9

Hassan ST, Xia E, Khan NH, Shah SMA (2019) Economic growth, natural resources, and ecological footprints: evidence from Pakistan. Environ Sci Pollut Res 26(3):2929–2938

He X, Adebayo TS, Kirikkaleli D, Umar M (2021) Consumption-based carbon emissions in Mexico: an analysis using the dual adjustment approach. Sustain Prod Consum 27:947–957

Iqbal A, Tang X, Rasool SF (2022) Investigating the nexus between CO2 emissions, renewable energy consumption, FDI, exports and economic growth: evidence from BRICS countries. Environ Dev Sustain 1-30. https://doi.org/10.1007/s10668-022-02128-6

Johansen S, Juselius K (1990) Maximum likelihood estimation and inference on cointegration—with applications to the demand for money. Oxford Bull Econ Stat 52(2):169–210. https://doi.org/10.1111/j.1468-0084.1990.mp52002003.x

Kirikkaleli D, Güngör H, Adebayo TS (2022) Consumption-based carbon emissions, renewable energy consumption, financial development and economic growth in Chile. Bus Strateg Environ 31(3):1123–1137

Koengkan M (2017) Is the globalization influencing the primary energy consumption? The case of Latin America and Caribbean countries. Cadernos UniFOA 12(33):57–67

Koohi-Fayegh S, Rosen MA (2020) A review of energy storage types, applications and recent developments. J Energy Storage 27:101047

Kwakwa PA (2020) What determines renewable energy consumption? Startling evidence from Ghana. Int J Energy Sect Manage 15(1):101–118. https://doi.org/10.1108/IJESM-12-2019-0019

Kwakwa PA, Alhassan H (2018) The effect of energy and urbanisation on carbon dioxide emissions: evidence from Ghana. OPEC Energy Review 42(4):301–330

Kwakwa PA, Alhassan H, Adu G (2020) Effect of natural resources extraction on energy consumption and carbon dioxide emission in Ghana. Int J Energy Sect Manage 14(1):20–39. https://doi.org/10.1108/IJESM-09-2018-0003

Kwiatkowski D, Phillips PC, Schmidt P, Shin Y (1992) Testing the null hypothesis of stationarity against the alternative of a unit root: How sure are we that economic time series have a unit root? J Econom 54(1–3):159–178

Latif Z, Latif S, Ximei L, Pathan ZH, Salam S, Jianqiu Z (2018) The dynamics of ICT, foreign direct investment, globalization and economic growth: panel estimation robust to heterogeneity and cross-sectional dependence. Telematics Inform 35(2):318–328

Li Q, Cherian J, Shabbir MS, Sial MS, Li J, Mester I, Badulescu A (2021) Exploring the relationship between renewable energy sources and economic growth. The Case of SAARC Countries. Energies 14(3):520

Lin B, Agyeman SD (2019) Assessing Ghana's carbon dioxide emissions through energy consumption structure towards a sustainable development path. J Clean Prod 238:117941

Llanos C, Kristjanpoller W, Michell K, Minutolo MC (2022) Causal treatment effects in time series: CO2 emissions and energy consumption effect on GDP. Energy 249:123625

Maji IK, Sulaiman C, Abdul-Rahim AS (2019) Renewable energy consumption and economic growth nexus: a fresh evidence from West Africa. Energy Rep 5:384–392

Manisalidis I, Stavropoulou E, Stavropoulos A, Bezirtzoglou E (2020) Environmental and health impacts of air pollution: a review. Front Public Health 8:14

Menegaki AN (2011) Growth and renewable energy in Europe: a random effect model with evidence for neutrality hypothesis. Energy Econ 33(2):257–263

Menegaki AN, Tiwari AK (2017) The index of sustainable economic welfare in the energy-growth nexus for American countries. Ecol Ind 72:494–509

Menegaki AN, Tugcu CT (2018) Two versions of the Index of Sustainable Economic Welfare (ISEW) in the energy-growth nexus for selected Asian countries. Sustain Prod Consum 14:21–35

Menyah K, Wolde-Rufael Y (2010) Energy consumption, pollutant emissions and economic growth in South Africa. Energy Econ 32(6):1374–1382

Miao C, Fang D, Sun L, Luo Q (2017) Natural resources utilization efficiency under the influence of green technological innovation. Resour Conserv Recycl 126:153–161

Murshed M, Ahmed Z, Alam MS, Mahmood H, Rehman A, Dagar V (2021) Reinvigorating the role of clean energy transition for achieving a low-carbon economy: evidence from Bangladesh. Environ Sci Pollut Res 28(47):67689–67710

Omer AM (2009) Energy use and environmental impacts: a general review. J Renew Sustain Energy 1(5):053101

Østergaard PA, Duic N, Noorollahi Y, Mikulcic H, Kalogirou S (2020) Sustainable development using renewable energy technology. Renewable Energy 146:2430–2437

Pesaran MH, Shin Y, Smith RC (2001) Bounds testing approaches to the analysis of level relationships. J Appl Econ 16:289–326

Pfeifer A, Dobravec V, Pavlinek L, Krajačić G, Duić N (2018) Integration of renewable energy and demand response technologies in interconnected energy systems. Energy 161:447–455

Phillips PC, Perron P (1988) Testing for a unit root in time series regression. Biometrika 75(2):335–346. https://doi.org/10.1093/biomet/75.2.335

Pourreza A, Geravandi S, Pakdaman M (2018) Food security and economic growth. J Nutr Food Secur 3(3):113–115

Przychodzen W, Przychodzen J (2020) Determinants of renewable energy production in transition economies: a panel data approach. Energy 191:116583

Rahman ARA, Shaari MS, Masnan F, Esquivias MA (2022) The impacts of energy use, tourism and foreign workers on CO2 emissions in Malaysia. Sustainability 14(4):2461

Rahman MM, Kashem MA (2017) Carbon emissions, energy consumption and industrial growth in Bangladesh: empirical evidence from ARDL cointegration and Granger causality analysis. Energy Policy 110:600–608

Rahman MM, Velayutham E (2020) Renewable and non-renewable energy consumption-economic growth nexus: new evidence from South Asia. Renewable Energy 147:399–408

Rehman A, Ma H, Radulescu M, Sinisi CI, Paunescu LM, Alam MD, Alvarado R (2021) The energy mix dilemma and environmental sustainability: interaction among greenhouse gas emissions, nuclear energy, urban agglomeration, and economic growth. Energies 14(22):7703

Sadiq M, Shinwari R, Usman M, Ozturk I, Maghyereh AI (2022) Linking nuclear energy, human development and carbon emission in BRICS region: do external debt and financial globalization protect the environment? Nucl Eng Technol. https://doi.org/10.1016/j.net.2022.03.024

Sahoo M, Sahoo J (2022) Effects of renewable and non-renewable energy consumption on CO2 emissions in India: empirical evidence from disaggregated data analysis. J Public Aff 22(1):e2307

Salim RA, Hassan K, Shafiei S (2014) Renewable and non-renewable energy consumption and economic activities: further evidence from OECD countries. Energy Econ 44:350–360

Saud S, Baloch MA, Lodhi RN (2018) The nexus between energy consumption and financial development: estimating the role of globalization in Next-11 countries. Environ Sci Pollut Res 25(19):18651–18661

Sebri M (2015) Use renewables to be cleaner: meta-analysis of the renewable energy consumption–economic growth nexus. Renew Sustain Energy Rev 42:657–665

Shahbaz M, Lahiani A, Abosedra S, Hammoudeh S (2018a) The role of globalization in energy consumption: a quantile cointegrating regression approach. Energy Econ 71:161–170

Shahbaz M, Shahzad SJH, Mahalik MK (2018b) Is globalization detrimental to CO2 emissions in Japan? New threshold analysis. Environ Model Assess 23(5):557–568

Shin Y, Yu B, Greenwood-Nimmo M (2014) Modelling asymmetric cointegration and dynamic multipliers in a nonlinear ARDL framework. Festschrift in honor of Peter Schmidt. Springer, New York, NY, pp 281–314

Singh N, Nyuur R, Richmond B (2019) Renewable energy development as a driver of economic growth: evidence from multivariate panel data analysis. Sustainability 11(8):2418

Soava G, Mehedintu A, Sterpu M, Raduteanu M (2018) Impact of renewable energy consumption on economic growth: evidence from European Union countries. Technol Econ Dev Econ 24(3):914–932

Song C, Bilsborrow R, Jagger P, Zhang Q, Chen X, Huang Q (2018) Rural household energy use and its determinants in China: how important are influences of payment for ecosystem services vs. other factors? Ecol Econ 145:148–159

Temiz Dinç D, Akdoğan EC (2019) Renewable energy production, energy consumption and sustainable economic growth in Turkey: a VECM approach. Sustainability 11(5):1273

Wang Q, Wang X, Li R (2022) Does urbanization redefine the environmental Kuznets curve? An empirical analysis of 134 Countries. Sustain Cities Soc 76:103382

Wang Z, Li Y, Cai H, Wang B (2018) Comparative analysis of regional carbon emissions accounting methods in China: production-based versus consumption-based principles. J Clean Prod 194:12–22

Widiyanti M, Sadalia I, Irawati N, Hendrawaty E (2019) Determining firm's performance: moderating role of CSR in renewable energy sector of Indonesia. Pol J Manag Stud 19

Zafar MW, Saleem MM, Destek MA, Caglar AE (2022) The dynamic linkage between remittances, export diversification, education, renewable energy consumption, economic growth, and CO2 emissions in top remittance-receiving countries. Sustain Dev 30(1):165–175

Zhang J, Wang B, Latif Z (2019) Towards cross-regional sustainable development: the nexus between information and communication technology, energy consumption, and CO 2 emissions. Sustain Dev 27(5):990–1000

Zhao Q, Chen Q, Xiao Y, Tian G, Chu X, Liu Q (2017) Saving forests through development? Fuelwood consumption and the energy-ladder hypothesis in rural southern China. Transform Bus Econ 16(3)

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