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RESEARCH ARTICLE

Threshold non-linear relationship between globalization, renewable energy consumption, and environmental degradation: evidence from smooth transition models

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Abstract

The study intends to explore the following objectives: initially, to examine the non-linear connection between globalization, renewable energy consumption, and environmental degradation. Secondly, to evaluate the role of globalization in increasing or decreasing the carbon emission at the threshold level for different income countries. Panel smooth transition regression (PSTR) is an econometric technique that has been applied for estimation utilizing the data from 1995 to 2017. Results signify that the globalization and environmental degradation have non-linear connection and depends on different regimes. Moreover, on the basis of estimation, it is considered that the effect beyond the threshold level can be damaging, whereas less than the threshold level globalization is positively related to carbon emission. Hence, the inverted U-shaped relation denotes that at a specific level, the rise in globalization reduces carbon emission, but later, a specific level globalization accumulates carbon emission. Carbon emission has non-linear and regime-dependent relation to economic development and renewable energy consumption. The study provides recommendations that can assist policymakers.

Keywords Globalization · Renewable energy consumption · Trade openness · Carbon dioxide emission · GDP · PSTR model

Introduction

The growth rates have been immensely increased over the years, due to which it has become an alarming issue for every country. To achieve economic development, various countries have become part of the economic cooperation agreement that aims to accumulate globalization around the globe (Zaidi et al. 2019). Among which, Asia-Pacific Economic Cooperation (APEC) is one of the contracts; the part of this agreement aims to improve the economy through trade openness, enhancing infrastructure, technological advancement, and others. For economic development, globalization is considered to be the main element that can provide assistance to share, communicate, and interact with businesses, financial institutes, ministry, and others throughout the globe at a larger pace. According to Shahbaz et al. (2017a), the structure of the procedure has changed compared to the 1970s, as it has become a vital tool to increase trade, capital flow, and technological advancement along with escalating knowledge about culture, social norms, and political values. It is not only the economy or businesses on which globalization has affected but also every single human being recognizes the importance of

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globalization in one or another kind or type such as the shift in usage of energy and potency, technological modification, capital investments, job opportunities, industrial growth, and enhancing environmental quality. Economic development and environmental quality enhancement are the most difficult issues to deal with. Hence, the part of the APEC contract can escalate the rate of growth through globalization without vandalizing the quality of the environment as the current phenomena.

The association of carbon dioxide emission and globalization is a difficult scenario for economic growth and environmental degradation from past years. The arguments on the carbon emission and environment propose mixed results mostly for time series and panel models, though it is claimed that global warming is the reason for the change in climate, due to which climate takes uncertain turns such as rain and carbon emission which are hazardous to humans (Zaman et al. 2016; Raza et al. 2017; Awodumi and Adewuyi 2020; Saint Akadiri et al. 2019; Raza et al. 2020c). Bekun et al. (2019a, b) analyze that carbon emission increases global warming, and maintaining environmental quality is difficult to sustain the attributes of living similarly for scholars, ministry, and governing powers of the countries contributing to this cause. Additionally, globalization has reduced the barriers between the developed and developing countries through capital flow, the investment in environmentally friendly technological innovations. Ultimately, globalization has provided a way for different income countries to interact and communicate but at the cost of environmental damage (Shahbaz et al. 2019).

While promoting the globalization benefits, it is examined that the scenario is not hazardous for the environment, hence it decreases the emission of carbon dioxide. However, some claim that it does not have reducing effects but it is damaging as it increases global warming by increasing the corrosion which is caused by carbon dioxide emission. Also, globalization increases the chances of production procedures which generates carbon, leading to degradation of the environment because the process of production and energy consumption for procedure remains unchanged. Shahbaz et al. (2017b) and Wijen and Van Tulder (2011) consider that globalization for developed countries enhances the growth of the economy but also speeds up natural resources reduction and environmental degradation in these economies.

Furthermore, countries have to face not only the increase in carbon emission but also the adverse impact of greenhouse gasses; however, various countries are focusing to emphasis on reducing the ratio of carbon emission and formulate policies to achieve the objective of reduction. Tang et al. (2015) stated that generally, the developed economies such as European Union countries have imposed strict rules and regulations regarding emission along with planned policies to reduce the emission of greenhouse gasses. According to UNFCCC (2011), compared to developed economies, the emerging ones have weak laws of environmental quality control as these economies do not exercise strict emission policies, due to which they have to face the consequences in terms of environmental degradation. Also, emerging economies are held responsible for polluting the environment more compared to advanced economies. Hence, due to the inequality among environmental control policies, the industries result in availing benefit on production cost and low-cost labor by opting for developing or underdeveloped countries that pollute the environment leading to environmental degradation as they have lax environmental laws that reduce the environment-related expense. Moreover, the report of The World Resource Institute's CAIT Climate DATA Explorer (WRI 2014) revealed that various developed counties argue that due to emerging countries, the rise in carbon emission activities has increased, whereas advanced economies such as OECD countries are to be blamed for higher carbon emission, although it is seen that carbon emission is reducing in OECD countries, but these economies alone produce about 40% of overall carbon emission because of energy consumption (Paramati et al. 2020).

On the other hand, developed economies purchase goods and services from emerging ones that indicate that the higher emission in emerging economies balances the decrease in emission in developed economies as the emission transfers from developed to developing countries. Also, the study of Ghosh (2010) supports the findings of past studies by identifying that emerging economies usually suffer because of globalization as they have weak environmental regulatory bodies and laws, due to which such economies have to bear the severe consequences in terms of pollution and increase in carbon emission. Secondly, it is significant to also consider the factors linked to the consumption of renewable energy because of the higher risk related to the environment in cases of climatic change and global warming (Padhan et al. 2020). Due to the ongoing changes in the environment, it is believed that the demand for renewable energy might increase in the coming years around the globe (Omri and Nguyen 2014). Some studies claim that globalization influences the usage of energy in beneficial and adverse ways affecting environmental quality (Apergis and Payne 2010a; 2010b; Shahbaz et al. 2018). The study of Rahman and Miah (2017) emphasizes that globalization adversely affects the usage of energy mostly for emerging economies, while some of the past studies argue that globalization has made a massive change in terms of living standard and career opportunities at a massive level globally especially after 1991 along with social, economic, and political factors but mostly in Foreign Direct Investment (FDI), investment, and balance of trade.

Therefore, a strong infrastructure of globalization enhances economic growth and would support to shift towards renewable energy (Shahbaz et al. 2016a). However, the shift in usage of energy resources can be reduced or can increase

relying on globalization. Belaïd and Zrelli (2019) consider that the effect of globalization can better be understood by analyzing international operations and FDI. Certainly, a huge amount of funding is necessary for technology and to encourage the use of renewable energy resources by multinational companies. Secondly, components of trade can deliver desired results for promoting the usage of renewable energy resources. As the developed economies prefer to utilize the resources having less carbon for energy production purposes, particularly, the usage of renewable energy can be promoted through employing advanced technology, trade openness, and others. Currently, developed economies emphasize the effects of globalization on the quality of the environment comparative to economic factors because of the consumption of low carbon emission resources required for productivity.

Moreover, energy is another vital element to achieve the objective of economic growth. Renewable energy usage contribution has been examined, and it is suggested that it has an undeniable part in generating carbon dioxide emission which affects the usage of renewable energy. The need for renewable energy consumption has escalated for past years and is expected to boost in the coming years on daily basis. The increase in the need for energy consumption is determined to be the main cause of the population growth; the standard of living and increase in effectiveness are a few of the causes of expansion in the energy sector. The figures suggest that the cumulative usage of energy throughout the globe has been raised particularly because of the reliance on fossil fuel resources. The rise in the demand for fossil fuel resources multiples the chances of carbon emission in the environment which increases environmental degradation and global warming. It is considered that carbon emission is the main source of global warming and hazardous to the environment. The usage of energy decreases greenhouse gasses, although the use of uncontaminated energy has not surpassed the stated level to decrease the production of carbon dioxide (Menyah and Wolde-Rufael 2010), while renewable energy generation can decrease the risk of prospective damage to the environment, hence it can be shifted from fossil fuel resources to eco-friendly energy consumption but it is difficult. The complications for shifting from fossil fuel to eco-friendly energy can be at the standard of output. Various investment issues come in the way of green energy generation which can be at the level of the initial cost, production cost, and arrangements. The demand for strong investment can assist to evaluate the supply of the required sum, risk control, and the ability to pay off debts. Monetary institutions can also contribute to this purpose by arranging funds needed.

Khan et al. (2020) suggest that stable monetary institutions can also invest in developing sectors although primitive monetary institutions decrease the chances of industrial development. Monetary markets are a vital part of an economy, and hence they contribute to enhancing environmental quality (Zhang 2011). Thus, developed financial institutes are of immense importance for economic development as they can assist in decreasing the ratio of carbon emission in several ways. According to Islam et al. (2013), a strong financial structure empowers the economy to allocate capital into the ventures working for the betterment of the environment, as the strong financial structure can aid in the process to enhance environment-friendly products that can direct to develop an outlay of energy and reduce carbon emission. Next, the government globally is modifying the configuration of industries by introducing various ventures and schemes for environmental safety to enhance the environment. To make the action a success, stable financial structure is necessary (Tamazian et al. 2009). Additionally, the study of highlights that stock exchange–listed companies must abide by the environmental laws to achieve the objective of decreasing the carbon emission.

Given in the stated context, the study analyzes the following research objectives: is globalization advantageous for the quality of the environment in high-, upper-middle-, lower-middle-, and low-income economies? The results to this objective contribute at two levels: first, we examine the connection between globalization and carbon emission for 154 economies labeled as high-, upper-middle-, lower-middle-, and low-income countries, and second, we analyze the effects of globalization and carbon emission in two regimes using the panel smooth transition regression (PSTR) model along examining the connection between these variables. The PSTR model is used to analyze the non-linear relationship between the variables in two conditions (Raza et al. (2020a); Raza et al. (2020b)). Though, if there is a significant relationship between the present level of globalization and earlier level of carbon emission and an insignificant connection between the present level of globalization and prospect carbon emission, then carbon emission will reduce with accumulation in globalization with time.

The paper is structured as follows: the "Literature review" section consist of literature review, the "Methodology" section includes a detailed note on the technique employed and data used for estimations, the "Data analysis" section reports the results of the estimation, and the "Conclusion" section summarizes the study.

Literature review

Various studies have attempted to analyze the connection between globalization and the quality of the environment (Saint Akadiri et al. 2020; Wang et al. 2020). Particularly, the relationship between globalization and carbon emission along with effects needs to be investigated along with different variations to assess environmental quality. Economic development and environmental degradation connection is of utmost

importance for various stakeholders such as business analysts, ecologists, and government (Chang et al. 2019). Therefore, to analyze the role of globalization and environmental quality relationship, pollution haven and pollution halo hypotheses are frequently used. The pollution haven model determines the fact that industries increasing pollution in developed economies mostly shifted to emerging economies having lax environmental laws that adversely affected the environment, and they become a haven for contamination businesses or sectors (Walter and Ugelow 1979; McGuire 1982). Likewise, the study of Doytch and Uctum (2016) also suggests that for relaxation, businesses working under strict environmental rules in the developed countries relocate to the developing countries having weak environmental laws leading to higher environmental degradation.

Some studies consider that trade and foreign direct investment are advantageous for recipient countries and for the betterment of environment because they emphasize hygienic practices, maintain quality standards, and use environmentally friendly technology to promote efficient consumption of energy and reduce carbon emission. According to the pollution halo hypothesis, the study of Stavropoulos et al. (2018) determines that for industries and recipient countries, trade and foreign direct investment are beneficial as they increase earnings but the environmental quality has to be compromised considering the pollution haven hypothesis. Hence, the halo hypothesis claims that FDI or relaxation promotes the initiation of green technology to enhance environmental rules and regulations for small-scale businesses (Sbia et al. 2014). Previous studies on the effects of deregulation on carbon emission also consider another point of view that is in terms of scale, technique, and composition effect. The scale effect proposes that trade openness influences the quality of the environment by improving economic development, thus the technique effect determines that trade deregulation encourages the shift towards green technology and improves environmental laws through which environmental standards can be maintained. Moreover, Acheampong et al. (2019) and Sbia et al. (2014) examine that the composition effect argues that trade openness can influence the quality of the environment through a change in the formation and procedure of production of the recipient country. Also, free trade can enhance the environment with efficient use of energy. But hypothetical and practical results on the impact of trade deregulations and foreign direct investment for the betterment of the environment are vague and inconsistent (Hakimi and Hamdi 2016).

The effects of trade deregulation on carbon emission are based on the level of composition, technique, and scale effect (Farhani et al. 2014). It is investigated that trade influences the economic development, while it insignificantly influences the quality of the environment in the case of EU countries analyzed from 1985 till 2016 (Balsalobre-Lorente et al. 2018). Sinha and Shahbaz (2018) examined the connection between renewable energy and trade openness with carbon emission for India utilizing the data from 1971 till 2015. The results suggest that renewable energy consumption along with trade openness has a negative effect on carbon emission.

Similarly, the study of Inglesi-Lotz and Dogan (2018) claims that renewable energy consumption has a positive yet significant impact on carbon emission but the usage of non-renewable energy has negative impact on the environment, although trade openness has an insignificant impact on carbon emission for Sub-Saharan Africa. To analyze the data from 1980 to 2011, the panel estimation technique was applied for cross-sectional dependence. The current study of Acheampong (2018) explores the association of trade openness with the quality of the environment for Sub-Saharan Africa, Asia-Pacific, the Middle East, and North African economies. The results indicate that through trade openness, environmental quality can be enhanced as it can assist in reducing the ratio of carbon emission worldwide.

Another study of Hu et al. (2018) examines the contribution of renewable energy to shrink the ratio of carbon emission in the short term and long term by the number of cointegration methods for emerging economies. The findings suggest that the use of renewable energy reduces the percentage of carbon emission for the short term but the increase in usage accumulates the production of carbon dioxide in the long term, although trade activities can also aid to decrease carbon emission and improve environmental quality. Thus, the connection between trade and carbon emission for different income group countries indicates different findings such as for middle-income economies, trade and carbon emission have a bidirectional relationship, but for high- and lower-income economies, trade and carbon emission confirm the unidirectional relationship. The estimations were estimated by applying the VEC causality technique for 105 economies (Shahbaz et al. 2017b).

Hence, in the case of OECD countries, the connection between trade openness and carbon emission was examined. The findings indicate that trade openness decreases the ratio of carbon emission as it is considered to be the key element along with other factors such as foreign direct investment that facilitate the process for the betterment of environmental quality in the OECD countries (Paramati et al. 2020). Furthermore, in terms of low-income economies, the effects of trade deregulation are considered to be the main element causing carbon emission, but for high-income economies, due to trade, the quality of environment can be improved (Chang et al. 2018; Liu et al. 2018; Can and Gozgor 2016). Similarly, the study of Wang and Zhang (2020) supports the findings of the previous study by proposing that trade activities assist in the process to reduce the level of carbon emission usually for high- and upper-middle-income economies, whereas for lower-middle-income economies, there is no effect on environmental

degradation, but trade openness in low-income economies leads to accumulation in carbon emission.

In the case of African countries, the connection between globalization and carbon emission was investigated for around 19 economies from 1971 till 2012. The estimations indicated that globalization can aid in the process to decrease carbon emission; however, the effect of globalization differs according to the economic condition (Shahbaz et al. 2016c). There are also contrast findings for FDI. The relationship between FDI and environmental degradation for Australia, Indonesia, Mexico, South Korea, and Turkey was determined. The results suggest that FDI can increase the emission of carbon; the results were estimated through PVAR (Bakirtas and Cetin 2017). Additionally, in the case of Turkey, it is considered that usage of energy and an escalation in foreign direct investment increase carbon emission, which is damaging for the environment. The results were estimated by applying the Autoregressive Distributed Lag (ARDL) approach by utilizing the data from 1974 till 2010 (Seker et al. 2015).

Zhang and Zhou (2016) investigate the effects of foreign direct investment on the emission of carbon for China. The findings suggested that in the case of China, foreign direct investment can be utilized to enhance the environmental quality which supports the pollution halo thesis through the STIRPAT framework. Another study states that foreign direct investment has a reducing effect on carbon emission for the Chinese economy (Jiao et al. 2018). Similarly, the study of Ning and Wang (2018) supports the findings of the previous study which considers that foreign direct investment provides assistance for the betterment of the environment. The results were estimated by applying the spatial econometric technique for 280 prefectural cities by utilizing the data from 2003 till 2012. Currently, it is explored that trade openness decreases emission of carbon in the case of Australia, Brazil, India, and the USA, but trade has accumulating effects on carbon emission in China; the results were estimated through sensitivity analysis (Acheampong and Boateng 2019). Moreover, the findings suggest that foreign direct investment can assist in reducing the emission of carbon in Brazil and China, but it can increase carbon emission in the USA, Australia, and India.

Consequently, the connection between globalization and environmental quality in terms of the African economy considers reducing carbon emission through globalization, while the results vary according to economic condition. The results were estimated by utilizing the data from 1970 to 2012 of 19 African countries (Shahbaz et al. 2016c). The Doytch and Uctum (2016) study examined the association of foreign direct investment with environmental quality for a worldwide sample. The results indicated that FDI is a favorable factor for advanced economies, whereas it has negative impact on emerging countries' environment. The role of foreign direct investment in improving environmental quality was analyzed from 1970 till 2010 through FMOLs and the ARDL technique to estimate the results. The findings indicated that foreign direct investment contributes towards environmental degradation for Brazil but has contrasting effects for Singapore (Kostakis et al. 2017). In the case of Morocco and Tunisia, the relationship between foreign direct investment and trade openness with energy consumption was determined through VECM models. The findings indicate that foreign direct investment and trade openness increase extensive usage of energy which damages the environment, but it enhances economic development and creates job opportunities (Hakimi and Hamdi 2016).

The study of Sinha and Shahbaz (2018) explored the connection between usage of renewable energy and trade openness on carbon emission for Pakistan from 1971 till 2015 through the ARDL technique. The results suggest that renewable energy consumption and trade openness have a significant yet inverse effect on carbon emission, while for some economies, foreign direct investment portrays no effect on carbon emission; the results were estimated through fixed effects and SUR methods, and same for the case of the number of cities in China, it is considered that foreign direct investment is not always the reason for an increase in carbon emission (Jugurnath and Emrith 2018; Liu et al. 2018).

Currently, some studies analyzed institutional variables to examine environmental pollution frameworks to avoid variable error bias. For instance, in the case of 109 countries, it is examined that democracy also contributes to environmental quality; countries having weak political structures are exposed to a higher risk of carbon emission (Joshi and Beck 2018). Similarly, another study suggests that democracy decreases the emission of carbon particularly in those economies which have the lowest corruption level. The results were determined for 144 countries using the data from 1970 to 2011 (Povitkina 2018). It is summarized that when economies suffer from extensive corruption levels, the structure of democracy becomes weak, due to which there is no significant effect on the emission of carbon. The data of 65 countries were collected; the data was analyzed through instrumental variables with the quantile regression technique along with fixed effects from 1981 till 2012. The results suggested the ministry philosophy can decrease carbon emission. Various studies have used different proxies for institutions such as economic freedom (Bhattacharya et al. 2017) and political stability (Al-Mulali and Ozturk 2015). Thus, it is clear that numerous studies have studied various variables to examine the impact on carbon emission with different techniques, whereas this study aims to contribute through analyzing globalization with trade openness to assess the effect on carbon emission which most of the literature has not considered. Also, the study objective is to estimate the findings with different techniques to gain a better understanding of the relationship among variables as this study applies the PSTR technique.

Methodology

The method which is practiced on the data file is the PSTR method proposed by Gonzalez et al. (2005). This method incorporates the dual function and can be termed as a non-linear homogenous panel or a linear heterogeneous panel framework. Hence, the method is simplification of the panel threshold regression (PTR) technique proposed by Hansen (2000). It is considered to be the fixed effect framework along with exogenous regressor and eliminates the heterogeneity issue in a non-linear framework. This model is the panel framework, in which coefficients vary with time and countries and consents for heterogeneity in the regression coefficients. Hence, suppose that the coefficients are in continual of an observable variable with a bounded function denoted as the transition function of the following variable and differ among higher states. The general PSTR function with two regimes is as follows:

$$y_{i,t} = u_i + \beta_0 x_{i,t} + \beta'_1 x_{i,t} g\left(q_{i,t}, \gamma, \mathrm{c}\right) + \varepsilon_{i,t} \tag{1}$$

These denotes that $i = 1,\ldots N$, $T = 1\ldots..T$. N refers to the number of cross-sections; T refers to the time measurements; $y_{i,\,t}$ demonstrate the independent variable; u_i portrays the fixed individual effect; $x_{i,\,t}$ is the vector of explanatory and control variables; $g(q_{i,\,t}, \gamma, \mathrm{c})$ is the transition function and relies on $q_{i,\,t}$ (the threshold variable), C (threshold parameter), and γ (parameter which defines the slope of the transition function); and $\varepsilon_{i,\,t}$ is the error term.

In this study, we aim to analyze the connection between globalization and carbon dioxide emission for a sample of annual panel data of 154 countries categorized as high-, middle-, and lower-income countries from 1995 till 2017. We consider that the connection between the two is non-linear, so the non-linear method is practiced to confirm the non-linearity of the association among globalization and carbon dioxide emission. The study also includes gross domestic product, renewable energy consumption, trade openness, and population as the potential variables that affect globalization and carbon dioxide emission (Acheampong et al. 2019). However, the general PSTR function is as follows:

$$\mathrm{CEM}_{i,t} = u_i + \mathrm{GDP}x_{i,t} + \alpha \mathrm{REN}_{i,t} + \alpha \mathrm{TO}_{i,t} + \zeta \mathrm{POP}_{i,t} + \varepsilon_{i,t} \tag{2}$$

i refers to the cross-section sum (in this study, it is 154 countries) and T is the duration (1995–2017). CEM is the carbon dioxide emission, GDP is the gross domestic product, and REN means renewable energy consumption. Then, TO is trade openness and POP is population. $g(q_{i,\,t}, \gamma, \mathrm{c})$ is the transition function in which $q_{i,\,t}$ is globalization and used as a threshold variable. The figure of the transition function varies between 0 and 1. Also, the equation is illustrated in terms of $q_{i,\,t}$ which is globalization (threshold variable); g describes the slope parameter and illustrates the transition's smoothness from one regime to another. According to Gonzalez et al. (2005) and Fouquau et al. (2008), the stated logistic function is as follows:

$$g\left(q_{i,t}, \gamma, \mathrm{c}\right) = \frac{1}{1 + \exp\left[-\gamma\left(q_{i,t} - c\right)\right]} \tag{3}$$

Hence, the parameter of threshold is denoted with C, and the slope of the transition function is estimated by $\gamma > 0$. The transition function can change into an indicator function when $\gamma \to \infty$. Furthermore, the $(q_{i,\,t}, \gamma, \mathrm{c}) = 1$, if $q_{it} \geq c$ and$g(q_{i,\,t}, \gamma, \mathrm{c}) = 0$ if $q_{it} < c$. The PSTR framework determines a panel model with fixed effects when $\gamma \to 0$. Due to the rise in threshold variable (globalization), carbon dioxide emission coefficients vary efficiently and progressively from first regime (β_0) equal to low levels of globalization to second regime ($\beta_0 + \beta_1$) corresponding to greater levels of globalization. Thus, within the PSTR model, the parameter relies on the threshold variable and differs across countries and duration. However, for the stated level of q (globalization), the reactivity of globalization to carbon dioxide emission for a provided number of countries (i) and time (t) is illustrated as follows:

$$\varepsilon_{it} = \beta_0 + \beta_1\, xg\left(q_{i,t}, \gamma, \mathrm{c}\right) \tag{4}$$

The process of three levels is stated to investigate the parameter of the PSTR framework. The first level is to test the linearity of the framework. This assessment illustrates the connection between the globalization and carbon dioxide emission which is sufficiently described by the quality linear framework (simple model) or by non-linear frameworks (PSTR method). H_0 is the linear model and is suitable, while H_1 is PSTR with two regime or one transition is suitable. The null hypothesis ($H_0 : \gamma = 0$) is tested besides the alternative hypothesis. According to Gonzalez et al. (2005), for the existence of the unidentified trouble in the parameter of the null hypothesis, the corrected estimation is non-standardized. To mitigate this problem, a regression function is proposed in which the transition function $(q_{i,\,t}, \gamma, \mathrm{c})$ in Eq. 1 is modified through the first-order Taylor expansion around $\gamma = 0$, and the new regression is stated:

$$y_{i,t} = u_i + \beta_0^* Z_{it} + \beta_1^* Z_{it} q_{it} + \beta_2^* Z_{it} q_{it}^2 + \ldots + \beta_m^* Z_{it} q_{it}^m + \varepsilon_{\mathrm{it}}^* \tag{5}$$

Consequently, in the stated function, the parameters $\beta_0^* \ldots \beta_m^*$ are accumulate of γ, and $u_{it}^* = u_{it} + R_m\, \beta_1\, Z_{it}$ in which R_m displays the remainder of the Taylor function. In this situation,

the estimation of $H_0 : \gamma = 0$ in Eq. 1 is related to check the H_0 in Eq. 5 $H_0^* = \beta_1^* = \ldots = \beta_m^*$. The Fischer LM test, Wald test, and likelihood test are utilized to check the null hypothesis of the linearity. They are estimated as follows:

$$\text{Fischer LM test} = \text{LM}_\text{f} = \frac{\frac{\text{SSR}_0 - \text{SSR}_1}{K}}{\frac{\text{SSR}_0}{\text{NT-N-K}}} \tag{6}$$

$$\text{Wald LM test} = \text{LM}_\text{W} = \frac{\text{NT}(\text{SSR}_0 - \text{SSR}_1)}{\text{SSR}_0} \tag{7}$$

$$\text{Likelihood ratio test} = -2\ [\log(\text{SSR}_1) - \log(\text{SSR}_0)] \tag{8}$$

Although, in null hypothesis (H_0), the addition of squared residuals is illustrated by SSR_0,in alternative hypothesis (H_1), the addition of squared residual is illustrated by SSR_1. $F(K, NT-N-K)$ distribution is utilized in the Fischer LM test, in which the number of explanatory variable is denoted by K, the number of countries is denoted by N, and time is referred by T. $x^2(K)$ distribution is used in Wald and likelihood tests.

Thus, if the null hypothesis of linear relationship is rejected, it means that the connection between the variables are non-linear and can be apprehended by the PSTR with at least two regimes. In the second level, the null hypothesis of no remaining non-linearity is checked. This analysis examines that the non-linear association between the variables can be apprehended by the PSTR with two regimes or not. The H_o is PSTR with two extreme regimes is appropriate whereas the H_1 is PSTR with at least three regimes is appropriate. The framework determined for this is as follows:

$$y_{i,t} = u_i + \beta_0 Z_{it} + \beta_1 Z_{it} g_1\left(q_{it,}; \gamma_1, c_1\right) + \beta_2 Z_{it} g_2\left(q_{it,}; \gamma_2, c_2\right) + \varepsilon_{it} \tag{9}$$

For the following equation, the null hypothesis is estimated as $H_0 : \gamma_2 = 0$. Over again, there is an issue of identification, and previously, it is mitigated by applying the Taylor expansion of $g_2\left(q_{it,}; \gamma_2, c_2\right)$ around $\gamma_2 = 0$. This proposes the following function:

$$y_{i,t} = u_i + \beta_0^* Z_{it} + \beta_1^* Z_{it} g_1\left(q_{it,}; \gamma_1, c_1\right) + \beta_{21}^* Z_{it} q_{it} + \ldots + \beta_{2m}^* Z_{it} q_{it}^m + \varepsilon_{\text{it}}^* \tag{10}$$

Thus, in Eq. 10, the null hypothesis $H_0 : \gamma_2 = 0$ of the PSTR framework with one transition or two regimes is paraphrased as $H_0^* : \beta_{21}^* = \ldots = \beta_{2m}^* = 0$. The following analyses are executed with Wald, Fischer, and likelihood tests. If the null hypothesis is accepted, the process is summarized and closed with statement that PSTR with one transition and two regimes is appropriate to examine the connection between the variables. On the other hand, if the null hypothesis is rejected, the test is performed again until the null hypothesis of no remaining non-linearity is accepted. When the regime is finalized at last, the non-linear square test is applied to measure the parameters of the model.

Data

To examine the connection between globalization and carbon emission, the yearly data that consists of the period from 1995 till 2017 is utilized for 154 different income group countries. The selection of the years entirely depends on the availability of data. Variables such as carbon dioxide emission is estimated by carbon dioxide emission per capita, renewable energy consumption is calculated by percentage of total final energy consumption, and the data for both variables was acquired from our world in data. While the data of other variables such as GDP is estimated through constant 2010 US$, trade openness is measured by merchandise trade (percentage of GDP) and population is denoted by total populations acquired from the World Bank. The data of globalization is estimated by using the KOF globalization index from KOF Swiss Economic Institute.

Data analysis

Descriptive statistics

The descriptive statistic test is applied on the data file. The general attributes of the dataset are illustrated by using this test. The results of descriptive statistics are exhibited in Table 1. The average value for full-sample carbon dioxide emission is 4.150 with the highest value of 36.001 and the lowest value of 0.061. The average globalization is 58.357 with the highest value of 91.300 and the lowest value of 22.800. The average renewable energy consumption is 34.406 with the highest value of 98.343 and the lowest value of 0.002. Trade openness average value is 66.548% with the highest value of 419.962% and the lowest value of 7.806%. The population displays an average value of 40.341 with the highest value of 1371.220 and the lowest value of 0.042.

Among high-, upper-middle-, lower-middle-, and low-income group categories, the highest average value of carbon dioxide emission is 9.306 with the highest value of 36.001 and the lowest value of 0.016. The average globalization is 75.495 with the highest value of 91.300 and the lowest value of 25.200, while for GDP, the highest is 91,565 US$ and the lowest is 183.548 US$. Then, the average value of trade openness is 78.664 along with the highest value of 419.962 and the lowest of 7.806. At last, the average value of the population is 62.751 with the highest value of 1371.220 and the lowest value of 0.042.

Table 1 List of countries

Low income		Lower-middle income		Upper-middle income		High income	
S. No.	Name	S. No.	Name	S. No.	Name	S. No.	Name
1	Benin	1	Angola	1	Albania	1	Australia
2	Burkina Faso	2	Bangladesh	2	Argentina	2	Austria
3	Central African Republic	3	Bhutan	3	Armenia	3	Barbados
4	Chad	4	Bolivia	4	Azerbaijan	4	Belgium
5	Congo, Dem. Rep.	5	Cambodia	5	Bulgaria	5	Canada
6	Ethiopia	6	Cameroon	6	Bosnia and Herzegovina	6	Chile
7	The Gambia	7	Comoros	7	Belarus	7	Croatia
8	Guinea	8	Congo, Rep.	8	Belize	8	Cyprus
9	Guinea-Bissau	9	Cote d'Ivoire	9	Brazil	9	Czech Republic
10	Haiti	10	Egypt, Arab Rep.	10	Botswana	10	Denmark
11	Madagascar	11	El Salvador	11	China	11	Estonia
12	Malawi	12	Ghana	12	Colombia	12	Finland
13	Mali	13	Honduras	13	Costa Rica	13	France
14	Mozambique	14	India	14	Dominica	14	Germany
15	Nepal	15	Indonesia	15	Dominican Republic	15	Greece
16	Rwanda	16	Kenya	16	Algeria	16	Hong Kong SAR, China
17	Sierra Leone	17	Kiribati	17	Ecuador	17	Hungary
18	Tajikistan	18	Kyrgyz Republic	18	Fiji	18	Iceland
19	Tanzania	19	Lao PDR	19	Gabon	19	Ireland
20	Togo	20	Lesotho	20	Georgia	20	Israel
21	Uganda	21	Mauritania	21	Equatorial Guinea	21	Italy
22	Yemen, Rep.	22	Moldova	22	Grenada	22	Japan
		23	Mongolia	23	Guatemala	23	Korea, Rep.
		24	Morocco	24	Guyana	24	Latvia
		25	Nicaragua	25	Iran, Islamic Rep.	25	Lithuania
		26	Nigeria	26	Jamaica	26	Netherlands
		27	Pakistan	27	Jordan	27	New Zealand
		28	Papua New Guinea	28	Kazakhstan	28	Norway
		29	Philippines	29	Lebanon	29	Panama
		30	Senegal	30	St. Lucia	30	Poland
		31	Solomon Islands	31	Sri Lanka	31	Portugal
		32	Tunisia	32	Maldives	32	Saudi Arabia
		33	Ukraine	33	Mexico	33	Seychelles
		34	Uzbekistan	34	North Macedonia	34	Singapore
		35	Vanuatu	35	Mauritius	35	Slovak Republic
		36	Vietnam	36	Malaysia	36	Slovenia
		37	Zambia	37	Namibia	37	Spain
		38	Zimbabwe	38	Peru	38	St. Kitts and Nevis
				39	Paraguay	39	Sweden
				40	Romania	40	Switzerland
				41	Russian Federation	41	Trinidad and Tobago
				42	Thailand	42	United Arab Emirates
				43	Turkmenistan	43	United Kingdom
				44	Tonga	44	United States
				45	Turkey	45	Uruguay
				46	St. Vincent and the Grenadines		
				47	Venezuela, RB		
				48	Samoa		
				49	South Africa		

Unit root test

The second test after descriptive statistics which is applied to explore the stationary properties of the variables is the unit root test. As the findings displayed in Table 2, all the variables are non-stationary at level but become stationary at first difference.

Panel smooth transition regression technique

In the PSTR model, the first step is to execute a linear test. This assessment that investigates the connection between the variables is comprehended by using the linear framework that is a standard panel model with fixed effect or by using the non-linear model that is the PSTR framework. The results of

Table 2 Descriptive statistics (before taking logarithm)

Variables	Mean	Median	Maximum	Minimum	Std. Dev.	Skewness	Kurtosis	Jarque–Bera	Probability	Observations
Full sample										
CEM	4.150	2.100	36.001	0.016	4.897	2.119	9.717	8501.046	0.000	3234
GLO	58.357	57.100	91.300	22.800	15.659	0.199	2.162	115.968	0.000	3234
GDP	11,318.720	4137.439	91,565.730	183.548	16,109.980	2.047	6.968	4349.973	0.000	3212
EN	34.406	26.479	98.343	0.002	30.271	0.608	2.014	330.599	0.000	3234
TO	66.548	56.599	419.962	7.806	41.164	2.974	17.875	34,573.330	0.000	3234
POP	40.341	8.442	1371.220	0.042	142.800	7.604	64.020	532,890.100	0.000	3234
Low income										
CEM	0.178	0.110	1.055	0.016	0.187	2.552	9.873	1410.817	0.000	462
GLO	41.250	41.300	54.900	25.200	7.039	− 0.071	2.120	15.292	0.000	462
GDP	568.234	531.645	1334.785	183.548	209.973	0.953	4.308	102.907	0.000	462
REN	78.784	85.291	98.343	0.862	20.649	− 2.451	9.419	1255.823	0.000	462
TO	46.155	40.953	169.665	7.806	21.624	1.751	8.079	732.766	0.000	462
POP	18.010	10.874	100.836	1.089	18.692	2.113	7.493	732.256	0.000	462
Lower-middle income										
CEM	1.147	0.738	13.485	0.072	1.408	3.299	17.177	8130.001	0.000	798
GLO	50.098	50.200	74.200	22.800	10.351	− 0.171	2.521	11.516	0.003	798
GDP	1624.249	1429.197	4308.416	341.891	782.657	1.015	3.646	146.881	0.000	777
REN	47.278	50.247	94.372	0.898	27.013	− 0.201	1.983	39.797	0.000	798
TO	65.685	61.298	169.568	15.907	29.074	0.613	2.982	50.050	0.000	798
POP	62.751	10.294	1310.152	0.078	186.205	5.318	31.741	31,227.090	0.000	798
Upper-middle income										
CEM	3.528	2.594	14.844	0.217	2.761	1.487	5.093	566.864	0.000	1029
GLO	56.703	57.000	80.900	31.600	10.234	− 0.053	2.461	12.953	0.002	1029
GDP	5652.359	4990.648	20,512.940	871.166	2919.039	1.276	5.448	535.689	0.000	1028
REN	21.580	15.517	88.096	0.002	19.907	1.121	3.590	230.442	0.000	1029
TO	65.243	58.305	225.412	12.315	30.692	1.504	6.279	847.854	0.000	1029
POP	48.013	5.466	1371.220	0.070	184.478	6.391	43.515	77,383.620	0.000	1029
High income										
CEM	9.306	8.351	36.001	1.073	5.455	1.834	7.958	1497.747	0.000	945
GLO	75.495	78.200	91.300	41.400	10.636	− 0.854	3.097	115.117	0.000	945
GDP	30,709.550	29,566.820	91,565.730	4786.356	18,102.770	0.748	3.306	91.743	0.000	945
REN	15.807	9.321	77.345	0.006	15.902	1.346	4.606	386.729	0.000	945
TO	78.664	58.772	419.962	14.296	59.006	2.616	11.410	3862.438	0.000	945
POP	23.981	7.230	320.635	0.042	48.299	4.223	23.145	18,789.130	0.000	945

CEM is carbon dioxide emission per capita, GLO is globalization index, GDP is gross domestic product per capita in thousands US dollars, REN is renewable energy consumption as percentage of total energy consumption, TO is trade openness measured as sum of trade as percentage of GDP, and POP is population count in millions

Source: Authors' Estimation

Table 3 suggest that null hypothesis is discarded and the alternative hypothesis is approved. This indicates that the gross domestic product exercises a non-linear association with globalization and carbon dioxide emission and can be examined by using the PSTR model.

Another step after the validation of non-linearity is to calculate the number of regimes, to make sure that no remaining non-linearity test is executed. The findings are displayed in Table 4, and the estimation illustrates the approval of the null hypothesis (the PSTR with one transition or two regimes), and the alternative hypothesis is eliminated (the PSTR with at least two transitions and three regimes). Generally, the PSTR method with two regimes or one transition is efficient to examine the non-linear relationship between globalization and carbon dioxide emission.

The estimations of the PSTR method are displayed in Table 5. The sign of the results is an essential aspect more

Table 3 Results of the Pesaran (2004) cross-sectional dependence test

Variables	Test statistics	*p* value
Full sample		
CEM	49.648	0.000
GLO	434.575	0.000
GDP	323.517	0.000
REN	9.994	0.000
TO	92.830	0.000
POP	283.970	0.000
Low income		
CEM	21.044	0.000
GLO	61.110	0.000
GDP	22.436	0.000
REN	31.907	0.000
TO	8.234	0.000
POP	68.928	0.000
Lower-middle income		
CEM	32.164	0.000
GLO	109.604	0.000
GDP	79.990	0.000
REN	25.685	0.000
TO	21.841	0.000
POP	93.708	0.000
Upper-middle income		
CEM	41.725	0.000
GLO	131.753	0.000
GDP	120.824	0.000
REN	10.156	0.000
TO	21.042	0.000
POP	62.851	0.000
High income		
CEM	25.059	0.000
GLO	131.723	0.000
GDP	111.432	0.000
REN	42.174	0.000
TO	52.455	0.000
POP	61.926	0.000

All variables are significant at 1% level

Source: Authors' Estimation

Table 4 Results of stationary analyses

Variables	Im, Pesaran, and Shin			
	I(0)		*I*(1)	
	C	*C* and *T*	*C*	*C* and *T*
Full sample				
CEM	1.511	− 0.895	− 37.562***	− 34.554***
GLO	− 0.144	− 0.434	− 33.667***	− 34.130***
GDP	5.131	− 1.230	− 24.813***	− 20.752***
REN	4.698	− 0.640	− 38.593***	− 34.439***
TO	− 0.119	− 0.325	− 38.484***	− 32.554***
POP	− 0.268	− 0.449	− 11.233***	− 12.092***
Low income				
CEM	1.305	− 1.190	− 13.458***	− 11.875***
GLO	3.241	− 0.797	− 14.986***	− 13.211***
GDP	2.117	0.506	− 11.183***	− 11.903***
REN	2.577	− 0.553	− 10.569***	− 9.802***
TO	− 0.454	− 0.930	− 17.485***	− 14.449***
POP	0.573	− 0.435	− 5.333***	− 7.842***
Lower-middle income				
CEM	− 0.951	− 0.488	− 18.259***	− 15.699***
GLO	− 0.524	− 0.727	− 15.229***	− 15.207***
GDP	9.202	− 0.578	− 13.244***	− 10.577***
REN	3.540	− 0.922	− 20.794***	− 17.029***
TO	− 0.833	− 0.619	− 15.752***	− 14.157***
POP	− 0.443	− 0.902	− 5.248***	− 3.3858***
Upper-middle income				
CEM	− 0.565	− 0.946	− 22.504***	− 20.922***
GLO	− 0.529	0.342	− 20.143***	− 21.389***
GDP	1.909	− 0.270	− 14.386***	− 11.107***
REN	− 0.639	− 0.175	− 22.130***	− 19.578***
TO	− 0.438	− 0.199	− 22.068***	− 18.504***
POP	− 0.796	− 0.852	− 6.579***	− 8.368***
High income				
CEM	3.332	1.734	− 19.825***	− 19.349***
GLO	− 0.485	− 0.470	− 16.839***	− 17.606***
GDP	− 0.579	1.927	− 10.864***	− 8.733***
REN	5.407	− 0.446	− 21.848***	− 20.788***
TO	− 0.780	− 0.103	− 21.504***	− 17.839***
POP	3.593	0.422	− 5.332***	− 5.061***

***, **, * indicate respectively the significance levels at 1%, 5%, and 10%

Source: Authors' estimation

Table 5 Linearity test

Threshold variable	Lagrange multiplies–Wald tests (LMW)		Lagrange multiplies–Fischer tests (LMF)	
	Statistics	*p* value	Statistics	*p* value
Low income	60.921	0.000	11.340	0.000
Lower-middle income	64.970	0.000	12.210	0.000
Upper-middle income	90.693	0.000	17.094	0.000
High income	86.712	0.000	15.228	0.000
Full sample	153.178	0.000	29.186	0.000

Ho: linear panel model

H_1: PSTR model with at least two regimes

Source: Authors' Estimation

than the calculated values as they cannot be interpreted directly in the PSTR framework (Fouquau et al. 2008). The estimations indicate that globalization has an insignificant yet progressive effect on carbon dioxide emissions in low-income group countries' regimes. As the countries progress from low-income group regimes to high-income group, the effect of globalization on carbon dioxide emission remains the same. The lowest threshold value of economic development above which globalization escalates the carbon dioxide emission is 1.671. Generally, the economic growth should be on average higher than 1.67% of carbon dioxide emission for the indication of the impact of globalization. The slope parameter (*C*) exhibits a value of 23.587, which refers that the transition from a weak regime to a strong regime increases. The focal point from the estimations is that there is a threshold point of economic growth above which globalization increases carbon dioxide emission.

To conclude, in a low-income group, the globalization and carbon dioxide emission are negatively connected with one another that is similar to the study of You and Lv (2018). The study suggests that globalization positively influences the environmental quality, as when globalization increases, it reduces carbon dioxide emission. The increase in earning through globalization in such income countries can be utilized by the government to enhance the quality of the environment. Also, globalization promotes the usage of energy technology while modifying the procedures and practices of the industrial sector (Stavropoulos et al. 2018).

The threshold variable of economic growth also exhibits similar findings. The estimations signify that gross domestic product effect on carbon dioxide emission is positive but has negative effect in the second regime. The findings are related to the study of Charfeddine and Mrabet (2017) that the increase in economic development results in enhancing the environment and reducing global warming which leads to a reduction in carbon dioxide emission. The threshold value of the gross domestic product is 2%.

Another variable renewable energy consumption exhibits a constant result for both the regimes. The consumption of renewable energy negatively affects carbon emission. The findings support the argument of Sinha and Shahbaz (2018) that renewable energy and trade openness have a negative relationship with carbon dioxide emission, as the trade openness portrays a positive connection within the first regime, but in the next regime, it changes to negative. Inglesi-Lotz and Dogan (2018) state that trade openness has a negative effect on carbon dioxide emission which supports the findings.

The outcomes for lower-middle-income countries for globalization indicate that it positively affects carbon dioxide emission, while in the second regime, the relationship changes to negative which is consistent with the results of low-income countries. The lowest threshold value of economic development above which globalization escalates the carbon dioxide emission is 1.711%. Usually, the economic development should be on average higher than 1.711% of carbon dioxide emission for the indication of the effects of globalization. Hence, the slope parameter (*C*) shows the value of 19.691, which denotes that transition increases from weak while progressing towards strong regime. The main point of the findings is that there is a threshold point of economic growth above which globalization increases carbon dioxide emissions.

To sum the findings, in lower-middle income, the association between globalization and carbon emission is negative which is similar to the study of Destek and Ozsoy (2015). The results indicate that globalization can eliminate carbon dioxide emissions. Moreover, it is examined that the increase in globalization increases financial development particularly in lower-income countries or developing ones through which carbon emission can be reduced (Mishkin 2009).

The threshold variable of economic development also shows similar results. The results indicate that the relationship between economic development and carbon dioxide emission is positive but later changes to negative in the second regime. The results support the claim of Shahbaz et al. (2016b) and Zafar et al. (2019). The findings suggest that due to economic development, the government can invest in environment-friendly technology which can assist to reduce carbon dioxide emissions.

Renewable energy consumption exhibits a constant result for both regimes. Renewable energy consumption has a negative effect on carbon emission. The consumption of renewable energy when increased mitigates carbon dioxide emission; additionally, economic growth and carbon dioxide emission are the main factors that encourage the consumption of renewable energy (Shafiei and Salim 2014; Sadorsky 2009). On the other hand, trade openness also shows the same results for both regimes. Trade openness has a positive effect on carbon dioxide emission which supports the pollution halo thesis. Moreover, it is reported that trade openness escalates carbon dioxide emission, particularly in low- and lower-income countries, while for high-income countries, trade plays an important part to enhance the quality of the environment (Chang et al. 2018). Likewise, the variable population exhibits a positive relationship with carbon dioxide emissions for both regimes. The results support the Khan et al. (2020) claim that due to increase in population, carbon dioxide emission increases especially in low- and lower-middle-income countries.

The findings of upper-middle-income countries for globalization show that it has a positive effect on carbon dioxide emission but is negative in the second regime. The minimum threshold value of economic growth above which globalization increases the carbon dioxide emission is 1.707%. Generally, the economic growth should be on average higher than 1.707% of carbon dioxide emission for the indication of the effects of globalization. Therefore, the slope parameter (C) exhibits a value of 14.882 which refers that the transition value from a weak regime to a strong regime has decreased. The results indicate that there is a threshold point of economic growth above which globalization increases carbon dioxide emission.

To illustrate the results of upper-middle income, the relationship between globalization and carbon dioxide emission is negative which supports the findings of Lee and Min (2014). The study suggests that globalization is an effective tool in enhancing the environmental quality in developed economies. As when globalization increases, it reduces carbon emission particularly in developed economies due to strict environmental rules. Secondly, the gross domestic product exhibits a negative relationship between economic growth and carbon dioxide emission. It denotes that when economic growth decreases, carbon dioxide emission increases or vice versa. Economic development strengthens the financial institutions which enhances development in monetary terms which assists in improving the quality of institutions and environment because of carbon dioxide emission decreases (Jalil and Feridun 2011).

Furthermore, renewable energy consumption shows negative results for both regimes. The results support the argument of Menyah and Wolde-Rufael (2010) which proposes that the consumption of renewable energy decreases the pollution which eventually decreases carbon dioxide emission. But in the case of trade openness, it exhibits a negative relationship with carbon dioxide emission for upper-middle-income countries. Jayanthakumaran et al. (2012) state that trade openness decreases the carbon dioxide emission, due to which trade openness should be promoted. At last, the population also exhibits a positive relationship with carbon dioxide emission in the second regime. It is supported by various studies that an increase in population increases carbon dioxide emission because of the increase in energy consumption, accommodation, traveling, and other needs.

The results of higher-income countries for globalization exhibit positive but then it changes to a negative effect in the second regime. The minimum threshold value of economic development above which globalization increases the carbon dioxide emission is 1.893%. Usually, the economic growth should be on average higher than 1.89% of carbon dioxide emission for the indication of the effects of globalization, although the slope parameter (C) shows the value of 24.527, which defines that the transition value from a weak regime to a strong regime has first decreased and then increased. The findings depict that after reaching a high economic developement regime the association between the globalization and carbon dioxide emission becomes positive and significant.

Subsequently, the finding for higher-income countries indicated that globalization has a negative effect on carbon dioxide emission; when globalization increases in such countries, it reduces the production of carbon dioxide. Christmann and Taylor (2001) determine that globalization increases foreign direct investment which provides opportunities to shift towards green and environment-friendly technologies for developed countries as well as it also provides chances for emerging countries if they promote globalization. Similarly, economic development also exhibits a negative relationship with carbon dioxide emission. According to Zaidi et al. (2019), economic development makes the financial institutions strong which aid in the process to eliminate carbon dioxide emission. Moreover, it is considered that high-income countries mostly spend on research and development which indicates the prosperity of economic growth as it helps to enhance the quality of the environment through improvement in green technology to mitigate carbon dioxide emission (Blanford 2009).

In the case of renewable energy consumption, it is seen that renewable energy consumption shows consistent results for both the negative regime. The increase in the consumption of renewable energy resources reduces carbon dioxide emission. Hanif (2018) suggests that the usage of fossil fuel resources increases carbon dioxide emission, while renewable energy consumption has the opposite effect on carbon dioxide emission, as through an increase in renewable energy resource, carbon dioxide effects can be reduced. Likewise, trade openness and population exhibit constant

results for both regimes, the positive effect. It indicates that the increase in trade openness and population increases carbon dioxide emission. The reason behind the increase in carbon dioxide emission due to increase in these both variables is because the rise in trade increases job openings and people prefer to settle in those countries where there are chances of higher living standards; the growth results in carbon emission as the need for residence, traveling, and others rises (Balsalobre-Lorente et al. 2018; Ben Jebli and Ben Youssef 2015; Acheampong et al. 2019).

The estimations for full-sample countries for globalization show positive and then negative for the second regime. Thus, the minimum threshold value of economic growth above which globalization increases the carbon dioxide emission is 1.801%. Economic growth should be on average higher than 1.8% of carbon dioxide emission for the indication of the effects of globalization. However, the slope parameter (C) exhibits a value of 38.921 which refers that the transition value from a weak regime to a strong regime has decreased at first and later increased. The results indicate that globalization increases carbon dioxide emission when economic development reaches above the threshold point.

To conclude, in full-sample countries, the globalization portrays negative effect on carbon dioxide emission which supports the findings of Zaidi et al. (2019). The study claims that the increase in globalization decreases carbon dioxide emission; additionally, globalization increases foreign direct investment to enhance economic development. The economically developed countries offer higher income through which brings social and environmental awareness which can aid in the process of decreasing environmental pollution (Zaidi et al. 2018).

Renewable energy consumption shows consistent results for both the regime that is negative which is similar to the study of Zhou and Li (2019). The study determines that to reduce carbon dioxide emission, the countries should shift their preference from consuming fossil fuel resources to renewable energy resources to enhance the quality of the environment. Moreover, renewable energy resource consumption has a negative relationship with carbon dioxide emission. Other variables such as trade openness and population also display consistent results for both the positive regimes. To elaborate, the results indicate that increase in trade openness and population increases carbon dioxide emission, which is similar to the findings of Khan et al. (2020). The study claims that trade openness and population decrease financial development due to which the government has less amount to allocate for the environment. Moreover, to increase financial development, government provides relaxation in rules and regulation to industries which increase carbon dioxide emission.

Conclusion

The study analyzes the relationship between globalization, economic development, and environmental degradation in the existence of renewable energy consumption and population for high-income, upper-middle-income, lower-middle-income, and low-income countries utilizing panel data from 1995 till 2017. The study applies the newly proposed econometric technique to examine the connection between the variables. A Persaran (2004) cross-sectional dependence method was applied to explore cross-sectional dependence between the variables. Second, the stationary analysis was conducted to study the stationary attributes through the unit root test. Then, the linearity test was conducted including the Wald and Fischer tests which were also part of the no remaining non-linearity test (Table 6). At last, PSTR model estimations for different income countries were conducted to analyze the relationship between the variables in two regimes (Tables 7, 8, 9, 10, and 11).

Hence, the results of the PSTR model estimation verify that the relationship between variables exists in terms of negative and positive. The findings of the model estimation suggest that (1) globalization for all the income countries is positive in the first regime which changes to negative in the second regime, which states that an increase in globalization decreases carbon dioxide emission. (2) An increase in economic growth decreases carbon dioxide emissions. (3) Renewable

Table 6 Test of no remaining non-linearity

Threshold variable	Lagrange multiplies–Wald tests (LMW)		Lagrange multiplies–Fischer tests (LMF)	
	Statistics	p value	Statistics	p value
Low income	12.221	0.270	1.111	0.352
Lower-middle income	9.494	0.486	0.880	0.5513
Upper-middle income	10.652	0.386	0.993	0.448
High income	13.940	0.178	1.319	0.214
Full sample	11.133	0.347	1.053	0.395

Ho: PSTR model with two regimes

H_1: PSTR model with at least three regimes

Source: Authors' Estimation

Table 7 PSTR model estimations of low-income countries

Variables	β_0	*t*-stats	β_1	*t*-stats
GLO	0.090*	1.811	− 0.301***	− 3.221
GDP	0.518*	1.942	− 0.708***	− 3.57
REN	− 0.767*	− 1.848	− 0.796*	− 1.923
TO	0.388	0.672	− 0.005	− 0.011
POP	0.379	1.072	0.515	1.342
Threshold (c)	1.671***	29.946		
Slope parameter (γ)	23.587***	2.692		

β_0 and β_1 stand for regime 1 and regime 2, respectively

***, **, * indicate respectively the significance levels at 1%, 5%, and 10%

Table 9 PSTR model estimations of upper-middle-income countries

Variables	β_0	*t*-stats	β_1	*t*-stats
GLO	0.243**	2.380	− 0.207**	− 3.027
GDP	0.733***	3.295	− 0.712***	− 4.152
REN	− 0.428**	− 2.059	− 0.166***	− 3.246
TO	0.092**	1.991	− 0.074*	− 1.834
POP	− 0.076	− 0.997	0.106	1.564
Threshold (c)	1.707***	8.245		
Slope parameter (γ)	14.882***	3.114		

β_0 and β_1 stand for regime 1 and regime 2, respectively

***, **, * indicate respectively the significance levels at 1%, 5%, and 10%

energy resource consumption decreases carbon dioxide emission and enhances the quality of the environment. (4) The effect of trade openness on carbon dioxide emission differs for different income countries. (5) An increase in population growth increases carbon dioxide emissions.

Managerial or practical implications

The findings depict that globalization, economic development, and renewable energy consumption all are negatively associated with carbon emission thus, confirming the pollution halo thesis. Also, different income countries i.e., high, upper-middle, lower-middle, and low-income countries show the same results. The increase in globalization leads to economic development that makes the financial and monetary institutes stable, leading to promoting and investing in renewable energy ventures and schemes resulting in reducing carbon emission. Globalization enhances economic development such as by increasing the chances of foreign direct investment leading to more capital flow within the economy that directs towards an increase in GDP, while the government would invest in the venture for the betterment of the environment along with spreading awareness for renewable energy consumption resulting in reducing carbon emission, whereas the effect of trade openness on carbon emission varies in different income countries, but it can be concluded that trade openness increases carbon emission. Thus, the increase in population accumulates the effect of carbon emission resulting in environmental degradation.

Various low-income and lower-middle-income countries have abundant fossil fuel reservoirs such as coal which makes these resources cost-efficient. Coal is the major source of energy production in these countries; therefore, the government should discourage the extensive usage of coal such as imposing taxes on the businesses that highly depend on these resources. To acquire the objective, government and policymakers should plan and formulate plans through which they can accelerate the process of globalization for better infrastructure, networks, and skilled labor to promote trading that can increase the flow of capital so that it can be utilized for funding the clean and green technology projects, while to reduce the contribution of trade openness in carbon emission, the government should take strict action against highly

Table 8 PSTR model estimations of lower-middle-income countries

Variables	β_0	*t*-stats	β_1	*t*-stats
GLO	0.202	1.335	− 0.361***	− 3.051
GDP	0.448**	2.045	− 0.736***	− 3.882
REN	− 0.644**	− 2.372	− 0.262**	− 2.058
TO	0.295***	3.115	0.1833*	1.798
POP	0.104***	2.880	0.066***	4.007
Threshold (c)	1.711***	5.209		
Slope parameter (γ)	19.691***	3.401		

β_0 and β_1 stand for regime 1 and regime 2, respectively

***, **, * indicate respectively the significance levels at 1%, 5%, and 10%

Table 10 PSTR model estimations of high-income countries

Variables	β_0	*t*-stats	β_1	*t*-stats
GLO	0.352***	3.487	− 0.412***	− 4.419
GDP	0.802***	4.228	− 0.830***	− 4.215
REN	− 0.558***	− 2.825	− 0.629***	− 3.120
TO	0.337**	2.117	0.352***	3.667
POP	0.157**	1.982	0.148	1.489
Threshold (c)	1.893**	16.225		
Slope parameter (γ)	24.527***	2.986		

β_0 and β_1 stand for regime 1 and regime 2, respectively

***, **, * indicate respectively the significance levels at 1%, 5%, and 10%

Table 11 PSTR model estimations of full-sample countries

Variables	β_0	*t*-stats	β_1	*t*-stats
GLO	0.414**	3.822	− 0.402***	− 3.249
GDP	0.581***	4.257	− 0.691***	− 4.018
REN	− 0.214**	− 2.375	− 0.499***	− 2.840
TO	0.077**	2.056	0.069**	1.987
POP	0.302**	2.412	0.334**	2.331
Threshold (c)	1.801***	13.146		
Slope parameter (γ)	38.921***	4.573		

β_0 and β_1 stand for regime 1 and regime 2, respectively

***, **, * indicate respectively the significance levels at 1%, 5%, and 10%

contaminating businesses in the lower-middle- and high-income countries.

Therefore, to reduce carbon content–containing products and environmentally friendly technology adaption projects require time and huge investment. The stable monetary and financial institutes can assist in developing infrastructure that promotes globalization and interests potential investors to fund the projects and schemes for economic growth along with promoting renewable energy resources and decreasing carbon emission.

Theoretical and empirical contributions

The novel contribution of this study is based on applying the new econometric technique. The results provided by using this technique indicate that trade openness increases carbon emission in the lower-middle- and high-income countries, whereas various study findings have indicated that trade openness reduces carbon emission in advanced economies, though carbon emission also increases due to trade openness because it provides better job opportunities and enhances the standard of living due that the rate of population increases that results in environmental degradation. Therefore, to reduce such effects, government should emphasize on renewable energy consumption.

Future recommendations

Thus, the findings of the study can vary due to different methodologies and economic condition as some of the countries were not part of the study due to the availability of data. Additionally, the countries are categorized according to the income level to assess the impact of a set of variables more evidently. Future studies can include other variables to evaluate the effect on the micro- and macro-level along with more countries.

Authors' contributions Yushi Jiang: Conceptualization, writing—original draft, writing—review and editing, supervision

Asadullah Khaskheli: Conceptualization, writing—original draft, writing—review and editing, data curation

Syed Ali Raza: Methodology, writing—original draft, writing—review and editing, software, formal analysis

Muhammad Asif Qureshi: Formal analysis, writing—original draft, writing—review and editing, data curation, methodology, formal analysis, software

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Data availability The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Compliance with ethical standards

Competing interests The authors declare that they have no competing interests.

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