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Dynamic linkages between globalization, human capital, and carbon dioxide emissions: empirical evidence from developing economies

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Abstract
This study examines the impact of human capital and globalization on carbon dioxide (CO_2) emissions for a sample of 78 developing countries, from Asia, Africa, and Latin America and the Caribbean, over the period from 1990 to 2016. As opposed to the existing studies in the literature, this study considers three types of globalization namely economic, social, and political globalization. The econometric analysis involves the use of the two-stage least squares-generalized method of moment method to account for endogeneity issues. The findings, overall, indicate that human capital development decreases CO_2 emissions in developing countries across all regions. In contrast, social globalization increases CO_2 emissions in all developing countries. Moreover, the empirical results also reveal that political globalization boosts CO_2 emissions in the Latin American and Caribbean region, but helps to curb CO_2 emissions in Asia, Africa, and in overall panel. Additionally, economic globalization significantly reduces CO_2 emissions in the Latin American and Caribbean region but increases CO_2 emissions in Asia, Africa, and in overall panel countries. Furthermore, human capital and globalization (in all three forms) jointly boost CO_2 emissions. Hence, in line with this major finding, we recommend that the globalization policies should also incorporate the human capital development agenda of the developing countries in order to comprehensively tackle the aggravation of CO_2 emissions.

Keywords Carbon dioxide emission · Human capital · Globalization · Developing countries · Endogeneity

1 Introduction

Climate change is a significant threat to the sustainability of environmental well-being around the world which, in turn, is likely to exert adverse economic consequences, as well (Kompas et al., 2018). Hence, tackling climate change has emerged as an utmost important task for the global economies which have pledged under the Paris Accord to limit

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the emissions of Greenhouse Gases (GHG) (Kamal et al., 2021; Usman, Jahanger, et al., 2022b; Murshed, 2021a). In the same vein, the Sustainable Development Goals (SDG) declarations have also stressed on combating climate change by inhibiting the emissions of GHG into the atmosphere (Pradhan, 2017; Qader et al., 2021; Usman, Anwar, et al., 2021). In particular, SDG7 calls for the global economies to make a transition towards clean energy (Murshed, 2021b, 2022) to lessen their energy consumption-based GHG emissions (Murshed, 2020; Huang et al., 2022; SDG, 2019).

Although all GHG are responsible for degrading the quality of the environment, emission of carbon dioxide (CO_2) has been extensively acknowledged as the major environmental-deteriorating factor due to CO_2 emissions accounting for a large portion of the global GHG emission level (Khalid et al., 2021; Balsalobre-Lorente et al., 2022; Ramzan et al., 2022; Murshed, 2021c). This is because CO_2 has the capacity to absorb and radiate heat; consequently, CO_2 emissions are linked with global warming-induced environmental concerns like rising sea levels (Mengel et al., 2018), excessive rainfall (Hui et al., 2018), melting of glaciers (Dixit et al., 2021), desertification (Vicente-Serrano et al., 2020), etc. Besides, the adverse effects of CO_2 emissions are multidimensional and do not limit to only environmental degradation. For instance, the aggravation of CO_2 emission levels can be assumed to affect economic well-being as well. Economic growth, if not environmentally sustainable, is doubtful to be sustained over a long period of time (Balsalobre-Lorente et al., 2021; Bandyopadhyay & Rej, 2021). Furthermore, CO_2 emissions, via the channel of climate change, also exert some social costs which marginalize the social well-being to a large extent as well. Among the major social issues, CO_2 emissions are assumed to trigger food insecurity by reducing agricultural productivity of lands (Hasegawa et al., 2018; Ahmad et al., 2022; Usman & Makhdum, 2021) and also affect human health (Wang, Zhou, et al., 2019). Consequently, considering these environmental and socio-economic hardships, policymakers worldwide are striving to unearth viable policies to control the aggravation of the global CO_2 emission figures.

The persistent rise in the aggregate CO_2 emission levels worldwide can be linked with the decisions of the global nations to globalize their respective economies. Globalization is extensively understood as helping individuals, firms, and economies to increase their outsourcing and trading of goods and services at the universal stage. Globalization connects developed and developing economies in sharing their knowledge, public policies, and culture (Raikhan et al., 2014; Yang et al., 2021). It benefits all economies in mitigating the rising problems of unemployment, poverty, and inequality (Nathan, 2018; Wade, 2004). The main objective of globalization process is to promote the economic growth of an economy (Santiago et al., 2020; Usman & Jahanger, 2021). It can also impose negative externalities to degrade environmental quality (Ulucak et al., 2020). This is because globalization results in economic growth; thus, globalization-induced economic growth can also be expected to influence environmental attributes (Yang et al., 2021). As a country becomes globalized, its economic activities tend to be stimulated which, in turn, stimulates energy demand, urbanization, and industrialization to trigger CO_2 emissions (Shahbaz et al., 2015). In contrast, globalization, especially through green technological spillovers, is also hypothesized to reduce CO_2 emissions to improve environmental quality (Balsalobre-Lorente et al., 2020; Usman & Hammar, 2021; Yang & Usman, 2021). Therefore, these equivocal environmental effects of globalization make the analysis of the dynamic relationship between globalization and CO_2 emissions important in the context of simultaneously achieving economic and environmental development.

Human capital development is another vital factor that influences the indicators of both economic and environmental well-being (Usman & Balsalobre-Lorente, 2022; Intisar et al., 2020; Khan et al., 2021). As far as the environmental effects are concerned, the development of human capital can improve energy efficiency and minimize energy consumption within the production process consequently, the energy use-related CO_2 emissions can be contained. Furthermore, it is also believed that human capital development also helps to curb CO_2 emissions increasing the level of energy competence (Kwon, 2009). As a result, several studies have confirmed that better education and training help to accumulate human capital which can be effective in abating GHG emissions to control global warming (Ireland & Clausen, 2019). In the industrial sector, a labor force with high levels of human capital is believed to ensure efficient use of energy for production purposes (Sadiq et al., 2022; Cagno & Trian's, 2013). Therefore, keeping into consideration the potential CO_2 emissions abating impacts associated with human capital development, it is worthwhile to scrutinize the human capital-CO_2 emissions nexus.

Against this milieu, this study utilizes a panel dataset of 78 countries over the period of 1990 to 2016 to specifically investigate the effects of globalization and human capital development on CO_2 emissions across developing economies. The focus is primarily on the developing nations because the majority of these nations are largely dependent on fossil fuels (Fadly, 2019). Besides, as a courtesy of having ample fossil fuel reserves, several of the developing countries are net-exporter of fossil fuels (Ansari & Holz, 2020; Usman et al., 2020). Hence, it can be expected that the developing countries share a large portion of the global CO_2 emission level; the low- and lower-middle-income countries collectively contribute to around 63% of global CO_2 emissions (World Bank, 2021). On the other hand, the environmental protection laws in developing countries, in comparison with those enacted in the developed nations, are relatively less strict. As a consequence, controlling CO_2 emissions is relatively more difficult in the context of developing countries.

Similarly, the globalization-CO_2 emissions nexus can also vary across the developing and developed nations. For instance, financial globalization facilitating the inflows of Foreign Direct Investments (FDI) has been seen to aggravate environmental quality in developing countries (Doytch, 2020). These studies emphasize that foreign investors take advantage of the poor environmental protection laws to outsource the production of pollution-intensive goods and services (Sadik-Zada & Ferrari, 2020). Therefore, the developing countries, as a result of financially globalizing their economies, are more likely to turn into pollution heavens for the developed nations to invest in. However, this is not always the case as globalization is found to degrade the environment in developed nations as well (Yang et al., 2021).

On the other hand, compared to the developed nations, the human capital level of most developing countries are relatively lower (Clarke, 2011). This is primarily due to the vast disparity in respect of expenditure on health and education across countries belonging to different income groups (Wu, 2013). For example, the average per capita healthcare expenditure in developed countries is 100 times more than that in developing countries (Raghupathi & Raghupathi, 2020). Moreover, the efficiency of public education expenditure is also comparatively lower in developing countries than that in developed counterparts (Miningou, 2019). Consequently, low human capital stocks in developing countries tend to reduce their energy efficiency and, therefore, hamper entrepreneurial performance (Wu, 2013). Besides, low human capital alongside the predominant fossil fuel dependency of these nations is often the reason behind the aggravation of CO_2 emission across the developing world. Hence, the adverse environmental effects associated with inappropriate globalization measures and poor quality of human development make it worthwhile to analyze the effects of globalization and human capital development on the CO_2 emission figures of the developing nations.

The contributions of this study are fourfold. First, although the globalization-CO_2 emissions nexus has been expansively explored in the literature (Le & Ozturk, 2020; Yang et al., 2021), the effects of different forms of globalization on CO_2 emissions in developing countries' context has relatively been less-researched in the existing studies (Destek, 2020). Although the aggregate globalization index is a good measure of globalization, the studies exploring the relationship between total globalization and CO_2 emissions do not emphasize the possible heterogeneous environmental effects associated with different types of globalization. Besides, several studies have controlled for macroeconomic factors like FDI inflows and trade openness in predicting the globalization-CO_2 emissions nexus (Aslam et al., 2021). However, since the aggregate globalization index is estimated up economic, social, and political globalization indices (Gygli et al., 2019), there is a possibility of the empirical model being subject to multicollinearity issues. This is because FDI inflows and trade openness are both key components of the economic globalization index; thus, the aggregate globalization index, FDI inflows, and trade openness index can be expected to be correlated. Therefore, to address such limitations in the empirical estimation strategies, this study scrutinizes the effects of economic, social, and political globalization and human capital development on CO_2 emissions without controlling for FDI inflows and trade openness.

Second, the majority of the previous studies have explored the individual impacts of globalization (economic, social, and political) and human capital on CO_2 emissions (Adebayo & Kirikkaleli, 2021; Yao et al., 2020). In contrast, this study adds to the literature by simultaneously evaluating the joint impacts of these disaggregated globalization indices and human capital on the CO_2 emissions figures of the developing nations of concern. In this regard, human capital is separately interacted with all three forms of globalization to predict their combined effects on CO_2 emissions. It is pertinent to ascertain these interactive impacts for adopting more comprehensive environmental policies. Third, many of the prior studies relevant to ours have not attempted to address the possible endogeneity issues in the data (Kalayci & Hayaloğlu, 2019; Usman, Balsalobre-Lorente, et al., 2021; Ke et al., 2022; You & Lv, 2018). However, not accounting for endogenous covariates within the model leads to the estimation of biased outcomes. Hence, taking into cognizance the possible endogeneity concern in the data, the Two Stages-Least Squares-Generalized Methods of Moments (2SLS-GMM) technique is employed to predict the long-run effects of globalization, human capital, and other key macroeconomic variables on CO_2 emissions. Lastly, since the previous studies have only focused on a single country or a small sample of countries and considered data over a short time period to explore the environmental effects associated with globalization and human capital development, the reliability of the findings documented in the literature can somewhat be doubted. In this regard, this study considers annual data of 78 developing countries spanning over 27 years (1990–2016) which makes the analysis relatively more comprehensive.

The rest of the paper is organized as follows: Sect. 2 reviews relevant studies documented in the literature. Section 3 presents the overall methodology used in this study concerning empirical model specification, data description, and the econometric estimation process. Section 4 presents and discusses the results while Sect. 5 provides the robustness analysis. Finally, Sect. 6 concludes and recommends policies.

2 Literature review

This section firstly provides a review of the theoretical framework concerning the globalization-human capital-CO_2 emissions nexus and then summarizes the empirical studies that have explored the impacts of globalization and human capital on CO_2 emissions.

2.1 Theoretical framework

In the contemporary era, achieving carbon-neutrality is embedded in almost all public policies (Jahanger et al., 2021a; Liu et al., 2021a; Ma et al., 2021; Wan et al., 2022). Accordingly, it is pertinent to identify the factors that can enable the global economies to decouple CO_2 emissions from economic growth so that these nations can achieve environmentally sustainable economic growth (Jahanger et al., 2022; Li et al., 2021). The linkage between globalization, human capital, and CO_2 emissions has gained much attention in the literature. Broadly speaking, globalization can be viewed as a process of transitioning from operating at the national level to the international level whereby different economies connect on several grounds. Hence, the ease at which people and goods and services flow across national boundaries can be termed as globalization. According to the Heckscher–Ohlin international trade model, a country globalizes its economy by exporting those goods and services in which it has a comparative advantage while importing those in which it has a comparative disadvantage in production. The Heckscher–Ohlin model was later modified under the Stolper–Samuelson trade theorem which also took into account the skill or human capital differentials among workers.

However, although all forms of globalization are conceptualized to promote economic growth (Jahanger et al., 2021b; Le Goff & Singh, 2014), several theories have highlighted both the positive and negative impacts of globalization on environmental quality. For instance, the Heckscher–Ohlin model of international postulates that globalization-driven international trade can encourage the fossil fuel abundant developing nations to specialize in production and export of pollution-intensive commodities; thus, economic globalization can be a means of developing the pollution-intensive industries whereby the CO_2 emissions levels are likely to rise (Jayadevappa & Chhatre, 2000). Under the same theoretical underpinning, clean energy-abundant nations can be expected to specialize and export clean commodities.

Similarly, the environmental impacts of financial globalization can also be understood from the Pollution Haven Hypothesis (PHH). It is believed that the PHH holds in the case of globalization-induced FDI inflows degrade the environmental quality of the FDI-hosting country due to the foreign funds being invested in dirty industries (Bataka, 2021). Conversely, the Pollution Halo Effect (PHE) asserts that FDI inflows, through technological spillover, can improve the quality of the environment in the host nations; consequently, globalization can drive down CO_2 emissions (Liu et al., 2021b). Therefore, these theoretical assertions tend to highlight that globalization generates both positive and negative environmental externalities.

On the other hand, human capital development is also assumed to affect the environmental attributes both positively and negatively. Linking a higher level of education to larger human capital stocks, it is believed that a country with more educated people can use their voice to demand better environmental quality from the government (Brasington & Hite, 2005). Besides, human capital development can be expected to facilitate technological innovation whereby more efficient use of energy can be ensured to curb the energy use-related CO_2 emissions (Li et al., 2022; Kwon, 2009). In the same vein, relatively more educated households are said to be more willing to pay for modern cooking fuels which are comparatively cleaner than traditional cooking fuels (Wassie et al., 2021). Furthermore, human capital development has also been acknowledged to trigger environmental welfare awareness among the people which, in turn, motivates them to undergo a clean energy transition to abate CO_2 emissions (Alvarado et al., 2021; Desha et al., 2015). Although human capital development is ideally effective in curbing CO_2 emissions, it can also trigger higher levels of emissions by stimulation economic growth (Haini, 2021).

Although both globalization and human capital are assumed to directly impact CO_2 emissions, certain indirect impacts can also be exerted. For instance, the globalization theories often associate higher degrees of globalization to the training of workers across national boundaries (Le Goff & Singh, 2014). Similarly, directing foreign capital flows to the health and education sectors in developing countries can be thought of as a credible mechanism of accumulating human capital (Le et al., 2019). Thus, the associations between globalization and human capital development imply that a joint environmental effect of these variables may exist. Thus, it is pertinent to explore the interactive impacts of globalization and human capital development on CO_2 emissions.

2.2 Empirical evidence

The nexuses between globalization, human capital, and CO_2 emissions have been documented in various recent empirical studies. The subsequent sub-sections summarize these studies.

2.2.1 The literature on the nexus between globalization and CO_2 emissions

Conceptually, world polity theory and ecological modernization theory argue that globalization can reduce CO_2 emissions by helping cultural, political, and social homogenization (Wang, Rasool, et al., 2019). Hence, several empirical studies have analyzed the effects of globalization on CO_2 emissions and other forms of environmental degradation (Shahbaz et al., 2018). Under these theoretical frameworks, the globalization-CO_2 emissions nexus has been examined through both country-specific and cross-country analyses and the results reported have been mixed.

Among the country-specific studies, Bilgili et al. (2020) recently studied the relationship between globalization and CO_2 emissions in the context of Turkey using the Markov regime-switching models by employing annual time series data from 1970 to 2014. The authors conclude that globalization decreases CO_2 emissions through the technological spillover effect. In another study by Wang et al. (2018), the associations between globalization, democratic quality, economic growth, and CO_2 emissions were explored in the context of Pakistan. Based on the findings, the authors reported that globalization drives greater CO_2 emissions to aggravate Pakistan's environmental well-being. Akadiri et al. (2019) investigated the causal association between economic growth, globalization, and CO_2 emissions and indicated that globalization boosts CO_2 emissions in Italy.

Jahanger et al. (2021b) examined the influence of energy consumption, globalization, autocracy, and democracy on environmental degradation in developing countries based on the system generalized method of moment (S-GMM) approach over the period from

1990 to 2016. The findings unveiled the negative impacts of greater globalization, poor democracy, and higher energy consumption on CO_2 emissions. Sethi et al. (2020) explored the relationships between financial development, globalization, economic growth, energy consumption, and CO_2 emissions in India from 1980 to 2015. Using the Vector Error-Correction Model (VECM) Granger causality test, the authors concluded that economic growth, energy consumption, and globalization directly contribute to higher CO_2 emissions, whereas financial development curbs the emission levels through the channel of economic growth.

Among the panel data studies, Zaidi et al. (2019) used data of 18 Asia Pacific Economic Cooperation (APEC) countries for the 1990–2016 periods to evaluate the effects of globalization on CO_2 emissions. Using the aggregate globalization index, and employing the Continuously Updated Bias Corrected (CUP-BC) and Continuously Updated Fully Modified (CUP-FM) ordinary least squares methods, the authors found that globalization is effective in abating CO_2 emissions while economic growth was concluded to be detrimental for the environment. Similarly using the aggregate globalization index, Salahuddin et al. (2019) scrutinized the globalization-CO_2 emissions, controlling for economic growth, urbanization, and energy poverty nexus concerning 44 Sub-Saharan African (SSA) for the 1984–2016 period. Applying different mean group estimators, the results showed that globalization cannot explain the variations in CO_2 emission levels while economic growth and urbanization boost CO_2 emissions in SSA.

In another similar study featuring 16 small island developing countries and covering the period from 1995 to 2014, Akadiri et al. (2020) employed the Granger causality analysis and found that the aggregate globalization index and CO_2 emission figures are not causally associated. Similarly for the Brazil-Russia-India-China-South Africa (BRICS) nations for the 1990–2015 period, Ulucak et al. (2020) used the aggregate globalization index and found statistical evidence regarding higher degrees of globalization adversely affecting the environment by boosting CO_2 emissions in the long run. In the context of 18 Latin American and Caribbean (LAC) nations over the 1990 to 2017 period, Nathaniel et al. (2021) used the augmented mean group panel regression analysis and found evidence of globalization boosting CO_2 emissions in these countries.

Although the abovementioned country-specific and cross-country studies have measured globalization using the aggregate globalization index, quite a few of the preceding studies have shed light on the association between different forms of globalization and CO_2 emissions. Among these, for a sample of nine SSA nations over the 1980–2019 period, Farouq et al. (2021) asserted that financial globalization is effective in promoting environmental well-being since it reduces CO_2 emissions across this region. On the other hand, Ahmed and Le (2021) explored the trade globalization-CO_2 emissions nexus for six Association of Southeast Asian Nations (ASEAN) states between 1996 and 2017. The findings showed that trade globalization boosts CO_2 emissions and, therefore, makes the ASEAN industries more pollution-intensive. It is to be noted that both financial and trade globalization indices are components of the economic globalization index (Gygli et al., 2019). Hence, focusing on the environmental impacts associated with the economic aspects of globalization, Wang et al. (2020) stated that economic globalization mitigates CO_2 emissions in the Group of Seven (G7) countries between 1996 and 2017. Conversely, Kalayci and Hayaloğlu (2019) concluded economic globalization boosts CO_2 emissions in the four North American Free Trade Agreement (NAFTA) member nations, namely the United States, Mexico, and Canada, between 1990 and 2015.

Several studies have also focused on the environmental impacts of political and social globalization. Among these, Khan et al. (2019) opined that social, political, and economic globalizations boost CO_2 emissions in Pakistan over the 1971–2016 periods. Conversely, Shahbaz et al. (2017), in the context of China for the 1970–2012 periods, opined that economic, social, and political globalizations curb CO_2 emissions. In another study on the 20 highest CO_2-emitting OECD nations between 1990 and 2016, Leal and Marques (2020) used the Driscoll-Kraay method and found evidence of political and economic globalization curbing and boosting CO_2 emissions, respectively. Similarly, Destek (2020) used data from 1995 to 2015 in the context of 12 Central and Eastern European nations and found economic and social globalization to boost CO_2 emissions while political globalization was evidence to curb CO_2 emissions. Hence, the findings documented in the studies by Leal and Marques (2020), Usman et al., (2022a) and Destek (2020) suggest that the environmental impacts concerning globalization can vary across the different forms of globalization.

2.2.2 The literature on the nexus between human capital and CO_2 emissions

A country's economic growth is firmly based on the stock of its human capital but it can also exert environmental externalities in the process. Afolayan et al. (2020) studied the causal relationship among the energy consumption, Human Development Index (HDI), and CO_2 emissions based on endogenous growth model over the period of 1980–2017 for the case of Nigeria. The results specified that energy consumption increases CO_2 emissions, whereas an improvement in the HDI (synonymous with a rise in the level of human capital development) reduces CO_2 emissions. For 15 Mediterranean region countries, Abdouli and Omri (2020) investigated the effects of FDI inflows, economic growth, and human capital on CO_2 emissions, and found that human capital, FDI inflows, and economic growth have a bidirectional causal relationship with CO_2 emissions. Similar evidence of a bidirectional causal association between human capital and CO_2 emissions in the case of Pakistan between 1971 and 2014 was reported by Bano et al. (2018). Besides, the authors added that human capital development is effective in curbing Pakistan's CO_2 emissions figures.

Among the other cross-country analyses of the human capital-CO_2 emissions nexus, Yao et al. (2020) scrutinized the long-run effects of human capital development on CO_2 emissions in 20 OECD nations over the 1870–2014 periods. The results from the pooled mean group, augmented mean group, and two-stages least squares models indicated that developing the stock of human capital can be considered an efficient mechanism of inhibiting CO_2 emissions. Khan (2020) used a large panel data set of 122 global nations between 1980 and 2014 to evaluate the human capital-CO_2 emissions nexus. The authors measured human capital in terms of educational attainment levels in the forms of primary, secondary, tertiary enrolment rates and mean years of schooling for the population of age 15. The results highlighted that human capital development initially worsens and later on improves environmental quality by increasing and decreasing CO_2 emissions, respectively.

In a recent study on newly industrialized countries over the 1979–2017 period, Rahman et al. (2021) used the panel fully modified ordinary least squares, dynamic ordinary least squares, and pooled mean group estimation techniques and found that human capital development mitigates CO_2 emissions. Haini (2021) recently showed that between 1996 and 2019 human capital development exerted adverse environmental consequences in the ASEAN countries. The authors asserted that human capital promotes economic growth of these Southeast Asian nations which, in turn, boosts CO_2 emissions. In another relevant study on the G7 countries over the 1991–2017 period, Hao et al. (2021) employed the cross-sectional augmented autoregressive distributed lag approach and found human capital development, environmental taxation, and clean energy use reduce CO_2 emissions.

Therefore, the reviews of the empirical studies, presented in Sects. 2.2.1 and 2.2.2, support our claims regarding the literature gaps this study aims to bridge.

2.2.3 The literature on various macroeconomic variables and CO_2 emissions

In addition to globalization and human capital, previous studies have also identified several other macroeconomic variables that can significantly influence CO_2 emissions. Hence, not controlling for these variables can generate omitted variables biased outcomes. Among these, CO_2 emission is assumed to be affected by economic growth, financial development, industrialization, urbanization, and capital and labor inputs.

Economic growth is postulated to be a double-edged sword due to exerting both favorable and adverse environmental consequences. Using data from 31 developing countries, Aye and Edoja (2017) used the dynamic threshold estimation technique and found economic growth initially reduces CO_2 emissions but boosts the emission figures afterward. On the other hand, linking financial inclusivity to financial development, Zaidi et al. (2021) concluded that financial inclusion helps to reduce CO_2 emissions in the context of 21 OECD countries over the 2004–2017 periods. Similarly, measuring financial development in terms of the respective shares of domestic credit given to the private sector in the GDP of selected African nations between 1985 and 2015, Yazdi and Ghorchi (2018) concluded that financial development boosts CO_2 emissions have bidirectional causal relationships.

On the other hand, structural change is also believed to influence CO_2 emissions. In this regard, using data of 31 Asian countries between 2004 and 2014, Le et al. (2020) used the Driscoll-Kraay estimation technique and found evidence of industrialization resulting in higher CO_2 emissions across Asia. Besides, the authors also concluded that urbanization is also an additional driver of CO_2 emissions in this region. In contrast, Muhammad et al. (2020), in the context of 65 BRI member countries over the 2000–2016 period, asserted that urbanization leads to a decline in CO_2 emissions. Besides, using the gross fixed capital formation figures to proxy capital accumulation and investment within the economy, Rahman and Ahmad (2019) revealed evidence of capital and CO_2 emissions being positively related. Furthermore, Lasisi et al. (2020) investigated labor input-CO_2 emissions nexus for OECD countries between 1995 and 2016 and found that the larger the size of the labor force the lesser the volume of CO_2 emissions.

Therefore, keeping into consideration the conclusions put forward by the preceding studies reviewed in this section (Sect. 2.2.3), we control for these critically important macroeconomic variables in our analysis of the effects of economic, social, and political globalization and human capital on CO_2 emissions from the perspective of the developing countries.

3 Empirical model, data, and estimation strategy

3.1 Empirical model and data

This study aims to investigate the impacts of different types of globalization and human capital on CO_2 emissions in the context of 78 developing countries (a list of sample countries is given in Appendix) using annual data between 1990 and 2016. The selection of the country sample and the period of the analysis are based on the availability of relevant data. In addition, to avoid the potential omitted variable bias issues within the estimation process, we also control for the environmental effects of economic growth, financial development, industrialization, urbanization, and capital and labor inputs. In line with the existing studies summarized in the literature review section (Sect. 2.2), we can specify the functional form of our empirical model as follows:

$$CO_{2it} = f\left(HC_{it}, EG_{it}, SG_{it}, PG_{it}, X_{it}, \varepsilon_{it}\right) \quad (1)$$

where CO_2 is CO_2 emissions; HC is the human capital index; EG is the economic globalization index; SG is social globalization index; PG is political globalization index; X is a vector of control variables including economic growth, financial development, industrialization, urbanization, and labor and capital inputs. Hence, the baseline empirical model considered in this study can be expressed on Model 1 as:

$$\begin{aligned} \text{Model 1}: \; CO_{2it} &= \beta_O + \beta_1 HC_{it} + \beta_2 EG_{it} + \beta_3 SG_{it} + \beta_4 PG_{it} + \beta_5 LGDP_{it} + \beta_6 FD_{it} \\ &+ \beta_7 FD_{it} + \beta_8 IND_{it} + \beta_9 URP_{it} + \beta_{10} LLF_{it} + \beta_{11} GCF_{it} + \varepsilon_{it} \end{aligned} \quad (2)$$

where subscript i represents cross-section units ($i = 1, 2, \ldots., 78$) and t represents time period (1990–2016); ε_{it} represents stochastic error term. The term β_0 is a constant term, and $\beta_1 \rightarrow \beta_{11}$ is the coefficient parameters to be estimated which would indicate the respective impacts of positive shocks to the explanatory variables on the per capita CO_2 emission figures of the developing countries of concern.

As far as the set of control variables considered in the model are concerned, FD represents financial development; URP represents is urban population growth which is used as a proxy of urbanization; GDP represents the per capita gross domestic product which is used to measure economic growth; IND represents industrialization; LF represents labor force which is used to measure labor inputs, and GCF represents gross capital formation which is a proxy for capital investments. Data for most of the variables were collected from the World Development Indicators database of the World Bank, except the data for the economic, political, and social globalization and human capital variables, which were obtained from KOF Swiss Economic Institutes (Dreher, 2006) and Penn World Table version 9.2 (Feenstra et al., 2015) database, respectively. Elaborate descriptions of all variables are given in Table 1.

Besides, to ascertain the possible heterogeneity of the findings across panels of developing countries from different global regions, we estimate the baseline model (model 1) for the sub-panels of Asian, African, and LAC countries. A disaggregated analysis is important because, although all these 78 countries are classified by the United Nations as developing economies, they may differ in terms of certain region-specific attributes. For instance, the degree of globalization can vary across the regions since there is a tendency between regional countries to offer preferential and free trade arrangements for one another. Similarly, political globalization is often existent among the regional nations. Besides,

Table 1 Variable descriptions and units of measurement

Variable	Symbol	Definition (unit of measurement)
CO_2 per capita	CO_2	CO_2 emission (metric tons per capita)
Human capital Index	HD	Human capital index, based on years of schooling and returns to education (index)
Economic globalization Index	EG	Economic globalization index, measured by the trade flow with other countries, FDI and Portfolio investment and restriction on these inflows and outflows (index)
Social globalization Index	SG	Social globalization index, measured by personal contact, information flows, and culture nearness (index)
Political globalization Index	PG	Political globalization index, measured by the embassy's numbers in other countries, International organization membership, UN Security Council missions meeting group and several treaties signed with other countries (index)
GDP per Capita	GDP	GDP per capita (Constant 2010 United States dollars)
Financial Development	FD	Domestic credit provided by the financial sector (percentage of GDP)
Industrialization	IND	Industry value added (percentage of GDP)
Urban Population Growth	UPG	Urban Population Growth per year (percentage)
Labor Force	LF	The total labor force (percentage of population)
Gross capital formation	GCF	Gross capital formation (percentage of GDP)
Human Development Index	HDI	The Human Development Index (HDI) is a composite index of education, life of expectancy and per capita income indicators (Index)

the regional countries are more likely to be culturally connected which could affect their regional political globalization indices as well.

Further, to check for interactive impacts of different forms of globalization and human capital on CO_2 emissions, we separately augment our baseline model (Model 1) with interaction terms between economic globalization and human capital (HC*EG), social globalization and human capital (HC*SG), and political globalization and human capital (HC*PG). The augmented versions of our baseline model can be expressed in Models 2, 3, and 4 as follows:

$$\text{Model 2}: \ \text{CO}_{2it} = \beta_O + \beta_1\text{HC}_{it} + \beta_2\text{EG}_{it} + \beta_3\text{SG}_{it} + \beta_4\text{PG}_{it} + \partial_1(\text{HC} * \text{EG})_{it} + \beta_5\text{LGDP}_{it} + \beta_6\text{FD}_{it} + \beta_7\text{FD}_{it} + \beta_8\text{IND}_{it} + \beta_9\text{URP}_{it} + \beta_{10}\text{LLF}_{it} + \beta_{11}\text{GCF}_{it} + \varepsilon_{it} \tag{3}$$

$$\text{Model 3}: \ \text{CO}_{2it} = \beta_O + \beta_1\text{HC}_{it} + \beta_2\text{EG}_{it} + \beta_3\text{SG}_{it} + \beta_4\text{PG}_{it} + \partial_2(\text{HC} * \text{SG})_{it} + \beta_5\text{LGDP}_{it} + \beta_6\text{FD}_{it} + \beta_7\text{FD}_{it} + \beta_8\text{IND}_{it} + \beta_9\text{URP}_{it} + \beta_{10}\text{LLF}_{it} + \beta_{11}\text{GCF}_{it} + \varepsilon_{it} \tag{4}$$

$$\text{Model 4}: \ \text{CO}_{2it} = \beta_O + \beta_1\text{HC}_{it} + \beta_2\text{EG}_{it} + \beta_3\text{SG}_{it} + \beta_4\text{PG}_{it} + \partial_3(\text{HC} * \text{PG})_{it} + \beta_5\text{LGDP}_{it} + \beta_6\text{FD}_{it} + \beta_7\text{FD}_{it} + \beta_8\text{IND}_{it} + \beta_9\text{URP}_{it} + \beta_{10}\text{LLF}_{it} + \beta_{11}\text{GCF}_{it} + \varepsilon_{it} \tag{5}$$

where $\partial_j (j = 1, 2, 3)$ are the coefficient parameters of the interaction terms to be forecasted. These parameters would indicate the interaction impacts between different forms of globalization and human capital on CO_2 emissions. Furthermore, we include all three interaction terms together in our baseline model and re-estimate it. The corresponding model can be expressed in Model 5 as follows:

$$\begin{aligned} \text{Model 5}: \ \text{CO}_{2it} = {} & \beta_O + \beta_1\text{HC}_{it} + \beta_2\text{EG}_{it} + \beta_3\text{SG}_{it} + \beta_4\text{PG}_{it} + \partial_1(\text{HC} * \text{EG})_{it} \\ & + \partial_2(\text{HC} * \text{SG})_{it} + \partial_3(\text{HC} * \text{PG})_{it} + \beta_5\text{LGDP}_{it} + \beta_6\text{FD}_{it} + \beta_7\text{FD}_{it} \\ & + \beta_8\text{IND}_{it} + \beta_9\text{URP}_{it} + \beta_{10}\text{LLF}_{it} + \beta_{11}\text{GCF}_{it} + \varepsilon_{it} \end{aligned} \tag{6}$$

Furthermore, we also conduct the robustness analysis in twofold. Firstly, the robustness of the findings is evaluated using a different model specification. It is an attempt to assess whether the findings are retained if we use a non-linear model specification instead of a linear one. Besides, it would also enable us to judge whether economic growth does have a monotonic impact on CO_2 emissions or not. Hence, in line with the theoretical underpinnings of the EKC hypothesis, we augment the baseline model (Model 1) with the squared term of the GDP variable (LGDPS) which can be expressed in Model 6 as follows:

$$\text{Model 6}: \ \text{CO}_{2it} = \beta_O + \beta_1\text{HD}_{it} + \beta_2\text{EG}_{it} + \beta_3\text{SG}_{it} + \beta_4\text{PG}_{it} + \beta_5\text{LGDP}_{it} + \delta_1\text{LGDPS}_{it} + \beta_6\text{FD}_{it} + \beta_7\text{FD}_{it} + \beta_8\text{IND}_{it} + \beta_9\text{URP}_{it} + \beta_{10}\text{LLF}_{it} + \beta_{11}\text{GCF}_{it} + \varepsilon_{it} \tag{7}$$

Secondly, the robustness of the findings is ascertained using an alternative indicator of human development. In this regard, following Afolayan et al. (2020), we estimate the baseline model (Model 1) by replacing the human capital index with the Human Development Index (HD) index. The corresponding model can be expressed in Model 7 as follows:

Table 2 Descriptive Statistics of the variables

Variable	Mean	Std. Dev	Min	Max
CO_2	3.775	7.952	0.021	70.042
HC	2.030	0.523	1.030	3.809
EG	49.119	14.650	14.262	95.285
SG	44.911	18.134	6.578	88.176
PG	62.602	16.204	15.427	92.820
LGDP	7.865	1.370	5.105	11.151
FD	43.902	34.409	−79.092	248.901
IND	75.988	50.106	−16.075	437.327
URP	3.183	1.921	−7.182	17.762
LLF	15.467	1.616	11.609	20.488
GCF	23.324	8.066	−2.424	61.4689

Table 3 Correlation between variables

Series	CO_2	HC	EG	SG	PG	LGDP	FD	IND	URP	LLF	GCF
CO_2	1										
HC	0.310*	1									
EG	0.478*	0.604*	1								
SG	0.435*	0.780*	0.740*	1							
PG	0.133*	0.348*	0.096*	0.302*	1						
LGDP	0.666*	0.739*	0.631*	0.792*	0.178*	1					
FD	0.182*	0.399*	0.398*	0.414*	0.311*	0.320*	1				
IND	0.217*	0.305*	0.644*	0.403*	0.136*	0.320*	0.241*	1			
URP	0.146*	0.369*	0.109*	0.297*	0.240*	0.208*	0.256*	0.028	1		
LLF	-0.032	0.028	0.128*	0.073*	0.279*	0.045*	0.299*	0.151*	−0.008	1	
GCF	0.126*	0.143*	0.178*	0.156*	0.156*	0.194*	0.175*	0.225*	0.057*	0.295*	1

* shows the significance at 1% level

$$\text{Model 7}: \; CO_{2it} = \beta_O + \beta_1 HD_{it} + \beta_2 EG_{it} + \beta_3 SG_{it} + \beta_4 PG_{it} + \beta_5 LGDP_{it} + \beta_6 FD_{it} + \beta_7 FD_{it} + \beta_8 IND_{it} + \beta_9 URP_{it} + \beta_{10} LLF_{it} + \beta_{11} GCF_{it} + \varepsilon_{it} \tag{8}$$

Table 2 presents the descriptive statistics (mean, minimum, maximum, and standard deviation) of the variables used in the study.

Table 3 presents the correlation matrix of all the variables considered in our models. According to Gujirati (1995), the rule of thumb for detecting multicollinearity is that if the zero-order or pair-wise correlation coefficient between two regressors is more than 0.85 percent, then there could be a severe multicollinearity problem. As can be seen from Table 3, all the correlation coefficients are less than 0.85; thus, it can be assumed that our empirical models are likely to be free from multicollinearity problems.[1]

[1] To further detect the presence of multicollinearity issues, we also conducted the Variance Inflation Factor (VIF) analysis for all our models and the found that the values to be less than 10 which indicate that the models do not suffer from multicollinearity concerns. For ensuring brevity we do not report them but the VIF analysis outputs can be made available upon request.

Table 4 Model 1 variables result

Variables	Full sample	Africa	LAC	Asia
HC	−48.01***	−1.310***	−5.327***	−23.64***
	(13.29)	(0.416)	(1.59)	(3.578)
EG	0.223***	0.00389	−0.0341***	0.233***
	(0.0619)	(0.00648)	(0.0117)	(0.0625)
SG	0.771***	0.0470***	0.0533*	0.316***
	(0.244)	(0.01)	(0.0293)	(0.103)
PG	−0.225***	−0.0320***	0.0316**	−0.118***
	(0.0498)	(0.00661)	(0.015)	(0.0366)
LGDP	10.18***	1.618***	2.206***	6.576***
	(1.528)	(0.136)	(0.214)	(0.626)
FD	−0.00564	0.00258	0.0104***	0.00314
	(0.0146)	(0.00233)	(0.00262)	(0.012)
IND	0.00799	0.00736	0.0142***	−0.0401***
	(0.0197)	(0.0024)	(0.00513)	(0.0117)
URP	−0.585	0.0208	−0.537***	1.055**
	(0.764)	(0.0316)	(0.114)	(0.442)
LLF	4.022***	0.652***	0.0391	0.798**
	(1.164)	(0.117)	(0.0961)	(0.365)
GCF	−0.148**	−0.0409***	0.133***	0.116**
	(0.062)	(0.0111)	(0.0204)	(0.0505)
Constant	−67.63***	−17.22***	−11.10***	−31.13***
	(11.09)	0.614	0.196	0.785
Wald Test	188.52	784.21	547.33	837.43
Prob. Value	0.0000	0.0000	0.0000	0.0000
Hansen J-statistics	4.25188	4.76626	1.47753	5.33495
Prob. Value	0.1193	0.0923	0.4777	7.81754
Wu–Hausman test	8.17637	7.81754	25.2332	11.8684
Prob. Value	0.0042	0.0052	0.0000	0.0006

The significant values of the Wald test statistics indicate that the models are correctly specified. The Wu-Hausman test statistic shows the potential presence of endogeneity, and the insignificant values of the Hansen J-statistics confirm the over-identifying restrictions. The robust standard errors are reported in parentheses. ***, ** & * indicate that the coefficients are significant at the 1%, 5%, and 10% levels, respectively

3.2 Estimation strategy

In this study, we apply the 2SLS-GMM technique to predict the coefficient parameters in all four models. This method accounts for issues of endogenous covariates in the model. Overlooking the endogeneity issues leads to the estimation of biased regression outcomes. In the 2SLS-GMM method, the first difference model is initially transformed using an instrumental variable matrix while in the next stage the transformed model is estimated using the generalized least squares method (Arellano & Bond, 1991). Besides, this method is appropriated only in the context of the number of cross-sections exceeding the time dimension of the data (i.e., N > T).

In the context of this study, the empirical models can be subject to endogenous issues since several previous studies have concluded that human capital and CO_2 emissions are bidirectionally associated (Abdouli & Omri, 2020; Huang et al., 2022; Bano et al., 2018). Hence, this reverse causation between these variables can be expected to create endogeneity problems in our models. Moreover, since this study considers 78 developing countries (N = 78) and uses data from 1990 to 2016 (T = 27), it can be said that the number of cross-sectional units is greater than the time dimension of the data set (i.e. N > T). Hence, considering the possible endogeneity issue and the relative magnitude of the number of cross-sections and time dimension, the choice of the 2SLS-GMM method is relevant.

4 Results and discussions

This section reports and discusses the findings from the 2SLS-GMM analysis. Table.4 reports the predicted coefficient parameters in the context of Model 1. The estimates indicate that human capital development curbs CO_2 emissions in developing countries and this finding is homogenous across the full sample of developing nations and the sub-samples of developing countries from Africa, Asia, and LAC. A 1% rise in the human capital index is found to reduce the per capita CO_2 emission figures for the full, African, LAC, and Asian panels by 48.01, 1.31, 5.32, and 23.64 metric tonnes, respectively. Hence, it can be said that human capital development is conducive to improving the quality of the environment in the cases of developing nations by reducing their CO_2 emission levels. This result is consistent with the recent findings of Yao et al. (2020) and Rahman et al. (2021) for OECD and newly industrialized economies, respectively, but contradicts the findings of Haini (2021) in the context of the ASEAN states. Given that the majority of the preceding studies have shown that CO_2 emissions would eventually be reduced through investment in education, training, and advanced technology to enhance the human capital stock, it shows that investment in human capital is an effective means of improving environmental quality in developing countries. This is especially important for the Sub-Saharan Africa region since as per a report by the World Bank (2017) around 89 million youths lacked adequate education or have dropped out of school.

Economic globalization appears to be positively associated with CO_2 emissions for the cases of the full and Asian panels and negatively associated for the LAC panel while for the African panel the predicted coefficient is statistically insignificant. A 1% rise in the economic globalization index is found to boost per capita CO_2 emission for the full and Asian panels by 0.22 and 0.23 metric tonnes while reducing CO_2 emissions by 0.03 metric tonnes for the LAC panel. Hence, overall, it can be said that economic globalization is not favorable for the developing countries which require these nations to green their existing economic globalization strategies. These results corroborate the finding of Destek (2019) in which the author revealed that economic globalization degrades environmental quality by triggering greater CO_2 emissions. On the other hand, the finding of the negative economic globalization-CO_2 emission nexus in the context of the LAC countries (albeit weak in magnitude and statistically insignificant) is in line with the study of You and Lv (2018) featuring 83 global countries.

The effects of social globalization on CO_2 emissions are positive and homogeneous across the full and sub-panels of developing countries. Specifically, the results show that a 1% increase in the social globalization index leads to an increase in per capita CO_2 emissions by 0.77 metric tonnes for the full panel, 0.05 metric tonnes for the African panel, 0.05

metric tonnes for the LAC panel, and 0.32 metric tonnes for Asian panel. These results are in line with the study of Khan et al. (2019) in the context of the developing South Asian nation Pakistan. Hence, in the context of the developing nations, it can be said that their social globalization policies are not aligned with their environmental development targets which require these nations to re-strategize the mechanism through which they can socially globalize their respective economies in an environmentally friendly way.

Turning to political globalization, the coefficient parameter estimates show that political globalization exerts positive environmental externalities for the full panel and the African and Asian sub-panels while generating negative environmental externalities for the LAC panel. Specifically, a 1% increase in the political globalization index is predicted to curb per capita CO_2 emissions by 0.23,0.03, and 0.12 metric tonnes for the full, African, and Asian panels, respectively, while boosting per capita CO_2 emissions by 0.03 metric tonnes for the LAC panel. These results, overall, imply that political globalization promotes international collaborations and interactions between formal and informal organizations, which can be expected to help the developing nations to adopt pollution-mitigating technologies for improving environmental quality. However, this is not true for the developing countries from the LAC region that is likely to be unable to reap the favorable environmental outcomes associated with political globalization. The international conflicts between the LAC countries could be one of the reasons why political globalization is found ineffective in facilitating the environmental well-being objectives of the associated nations. This result contradicts the conclusions made by Destek (2019) for Central and Eastern European nations which are mostly developed.

Furthermore, the coefficient parameters reported in Table 4 show that economic growth is detrimental to the environment across developing countries. The finding is homogenous across the full and the sub-panels of developing countries. This implies that the developing nations are more concerned about the growth of their respective economies and have traditionally traded-off higher economic growth with poor environmental quality. On the other hand, it can be seen that financial development boosts CO_2 emissions only in the context of the LAC panel while for the full, African, and Asian panels the coefficient estimate is statistically insignificant. Moreover, industrialization is found to boost CO_2 emissions for the LAC panel while curbing CO_2 emissions for the Asian panel. The coefficient parameter estimates also show that urbanization mitigates CO_2 emissions for the LAC panel while for the Asian panel urbanization is evidenced to boost CO_2 emissions. Furthermore, it can be seen that higher annual growth in the size of the labor force is associated with a rise in the CO_2 emission figures for the full, African, and Asian panels. In addition, capital accumulation and investment are found to curb CO_2 emissions for the full and African panels while boosting CO_2 emissions for the LAC and Asian panels.

In addition to examining the individual impacts of different types of globalization and hum capital on CO_2 emissions, we also assess the interaction effects of globalization and human capital on the CO_2 emission figures of the developing nations. The corresponding predicted coefficient parameters, in the context of Models 2–5, are reported in Table 5.[2] The results, in the context of Models 2, 3, and 4 for the full panel of developing countries, show that predicted interaction term coefficient parameters are positive and statistically significant. Hence, in light of these findings, it can be said that globalization, in all three

[2] We have also estimated models 2–5 for the African, LAC, and Asian sub-panels. However, since the findings are more or less homogeneous for the sub-samples only the findings in the context of the full panel are reported for ensuring brevity. The findings for the subpanels can be made available upon request.

Table 5 Models 2–5 variables result (considering full sample)

Variable	Model 2	Model 3	Model 4	Model 5
HC	−84.55***	−39.35***	−42.97***	−69.16***
	(29.06)	(9.800)	(10.03)	(14.91)
EG	−2.440***	0.0541*	0.0918***	−0.848***
	(0.923)	(0.0278)	(0.0191)	(0.213)
SG	0.268**	−0.804***	0.0584**	0.544***
	(0.108)	(0.243)	(0.0249)	(0.127)
PG	−0.0831**	−0.0258	−1.061***	−1.515***
	(0.0347)	(0.0254)	(0.255)	(0.323)
HCXEG	1.192***			0.473***
	(0.435)			(0.105)
HCXSG		0.467***		−0.245***
		(0.133)		(0.0571)
HCXPG			0.487***	0.689***
			(0.126)	(0.156)
LGDP	8.096***	6.465***	6.376***	7.017***
	(1.431)	(0.702)	(0.600)	(0.643)
FD	−0.0622**	−0.0169*	0.00243	0.000146
	(0.0280)	(0.00942)	(0.00549)	(0.00698)
TRD	0.0706**	0.0512***	0.0101	−0.0374***
	(0.0298)	(0.0161)	(0.00828)	(0.00759)
URP	−0.930	0.618*	0.654**	0.512*
	(0.777)	(0.369)	(0.302)	(0.264)
LLF	3.123***	1.636***	0.376**	0.0498
	(0.938)	(0.350)	(0.190)	(0.192)
GCF	−0.0795*	−0.0410	0.0102	0.110***
	(0.0449)	(0.0337)	(0.0266)	(0.0382)
Constant	54.18*	−7.686	28.34*	84.80***
	(32.23)	(8.027)	(16.62)	(26.77)
Wald Test	159.92	330.66	448.4	599.59
Prob. Value	0.0000	0.0000	0.0000	0.0000
Wu–Hausman test	7.37703	14.254	24.4271	37.3701
Hansen J-statistics	9.21951	10.2323	1.50055	0.050876
Prob. Value	0.1006	0.0689	0.4722	0.9970

The significant values of the Wald test statistics indicate that the models are correctly specified. The Wu-Hausman test statistic shows the potential presence of endogeneity, and the insignificant values of the Hansen J-statistics confirm the over-identifying restrictions. The robust standard errors are reported in parenthesis. ***, ** & * indicate that the coefficients are significant at the 1%, 5% and 10% levels, respectively

forms, and human capital development jointly boost CO_2 emissions to degrade environmental quality in the developing countries of concern. It implies that the adverse environmental impacts of globalization tend to dominate the favorable environmental impacts of human capital development; consequently, these variables jointly contribute to further emissions of CO_2. Therefore, from a policy perspective, it is ideal to align the globalization

Table 6 Variables results from Model 6 robustness analysis

Variables	Full panel	Africa	LAC	Asia
HC	−35.30***	−0.294***	−4.151***	−25.025***
	(9.623)	(0.0742)	(0.228)	(1.306)
EG	0.183***	0.00159	−0.0441***	0.2879****
	(0.0489)	(0.00135)	(0.00291)	(0.0339)
SG	0.533***	0.00529***	0.0225***	0.3562***
	(0.180)	(0.00191)	(0.00519)	(0.0378)
PG	−0.171***	−0.00193	0.0547***	−0.1573***
	(0.0575)	(0.00123)	(0.00359)	(0.0270)
LGDP	14.42***	2.094***	2.845*	7.087***
	(4.985)	(0.403)	(1.471)	(2.112)
LGDPS	−44.11	−0.170***	−0.176**	−1.256
	(45.63)	(0.0272)	(0.0832)	(1.335)
FD	−0.000259	−0.000247	0.00380***	0.0430
	(0.00952)	(0.000453)	(0.000812)	(0.04731)
IND	0.00662	0.000185	0.0257***	−0.0533***
	(0.0153)	(0.000373)	(0.00172)	(0.00715)
URP	−0.104	0.00945	−0.507***	1.559***
	(0.474)	(0.00616)	(0.0406)	(0.549)
LLF	2.969***	0.950***	0.169***	0.231***
	(0.881)	(0.181)	(0.0521)	(0.081)
GCF	−0.0999*	−0.00350***	0.217***	−0.1148***
	(0.0555)	(0.00119)	(0.0484)	(0.0202)
Constant	−13.54	6.934***	10.83*	−25.94
	(53.47)	(1.527)	(6.433)	(27.01)
Wald Test	300.57	285.180	310.500	275.326
Prob. Value	0.0000	0.0000	0.0000	0.0000
Wu–Hausman test	21.5519	25.275	20.119	23.670
Hansen J-statistics	4.48407	4.0711	5.420	4.294
Prob. Value	0.1062	0.114	0.113	0.125

The significant values of the Wald test statistics indicate that the models are correctly specified. The Wu-Hausman test statistic shows the potential presence of endogeneity, and the insignificant values of the Hansen J-statistics confirm the over-identifying restrictions. The robust standard errors are reported in parenthesis. ***, ** & * indicate that the coefficients are significant at the 1%, 5%, and 10% levels, respectively

policies with the human capital development policies so that these key variables collectively work to improve environmental quality by curbing CO_2 emissions. However, in the context of Model 5, an interesting finding is witnessed. The predicted coefficient parameters concerning Model 5, as reported in Table 5, show that when the empirical model controls for all three interaction term variables together, social globalization and human capital development jointly contribute to mitigating CO_2 emissions.

5 Robustness analyses

In this study, we employ two robustness check analyses. Firstly, the robustness of the findings is checked by re-estimating the baseline model using a non-linear specification by adding the squared term of GDP in the model. The inclusion of this squared term is in line with the assertion of the EKC hypothesis which postulates that although economic growth at first is detrimental to environmental welfare it goes on to enhance environmental welfare later on (Wang, Guo, et al., 2022). Hence, the EKC hypothesis holds if the economic growth-CO_2 emissions nexus is inverted U-shaped (Dong et al., 2018). The corresponding coefficient parameters of Model 6 are reported in Table 6.

The estimates reveal two key findings. First, it can be witnessed that the predicted signs of the coefficient parameters in the context of Model 6 (shown in Table 6) are consistent with the corresponding signs of the coefficient parameters in the case of Model 1 (shown in Table 4). Hence, this similarity can be considered as proof of the robustness of our findings across alternative model specifications. Second, as far as the authenticity of the EKC hypothesis is concerned, the findings reported in Table 6 reveal that for the full and Asian panels the EKC hypothesis does not hold as the predicted coefficient parameter attached to LGDPS is statistically insignificant. However, the EKC hypothesis is verified for the cases of the African and LAC panels since the predicted coefficient parameters attached to LGDP and LGDPS are positive and negative, respectively, and also statistically significant. This finding is in line with the conclusions put forward in the studies by Nosheen et al. (2021) and Dong et al. (2018) for selected APEC and Asian countries, respectively.

Since the EKC hypothesis was authenticated for the developing countries from the African and LAC regions, it can be asserted that these nations are likely to implement relevant policies to control their respective CO_2 emissions without adversely affecting the growth of their economies. However, since in most of these nations the CO_2 emission figures have aggravated with time, it gives an impression that these nations are yet to attain the threshold level of national income per capita which could economically empower them to implement the environmental protection policies effectively.

Moreover, the robustness of the findings is further checked by using HDI as an alternative indicator of human capital development and re-estimating the baseline model. The corresponding coefficient parameters in the context of Model 7 are reported in Table 7. The estimates show that a rise in the HDI helps to curb CO_2 emissions in the developing countries and this finding holds for both the full panel and the regional sub-panels. Specifically, a 1% rise in the HDI index is evidenced to mitigate the per capita CO_2 emissions for the full panel by 45.52 metric tonnes, for the African panel by 276.8 metric tonnes, for the LAC panel by 44.89 metric tonnes, and for the Asian panel by 17.90 metric tonnes. These findings corroborate the findings reported in the context of Model 1 which showed that a rise in the human capital index also contributed to lower CO_2 emission levels. In this regard, it can once again be claimed that our findings are robust against the use of alternative indicators of human capital development. Afolayan et al. (2020) also found evidence of a positive correlation between HDI and CO_2 emissions in the context of Nigeria.

Table 7 Variables results from Model 7 robustness analysis

Variables	Full sample	Africa	LAC	Asia
HC	−45.52**	−276.8**	−44.89**	−17.90***
	(19.79)	(129.2)	(22.69)	(6.151)
EG	0.113***	0.142	−0.0283***	0.0707***
	(0.0261)	(0.106)	(0.0106)	(0.0181)
SG	0.0694	0.843**	0.0977	0.112***
	(0.0725)	(0.376)	(0.0662)	(0.0307)
PG	−0.114***	−0.475***	0.0691**	−0.0625***
	(0.0191)	(0.0815)	(0.033)	(0.0137)
LGDP	7.649***	18.07***	4.182***	3.177***
	(1.287)	(5.51)	(1.205)	(0.539)
FD	0.0250***	−0.0326	0.000238	−0.0143**
	(0.00733)	(0.0319)	(0.00521)	(0.00566)
IND	−0.0230***	−0.0565***	0.00886	−0.0132***
	(0.00715)	(0.0151)	(0.00608)	(0.00425)
URP	1.319***	−0.341	−0.460***	0.137**
	(0.295)	(0.911)	(0.0831)	(0.0698)
LLF	0.728*	0.165	−0.0736	1.501***
	(0.374)	(0.57)	(0.103)	(0.32)
GCF	0.0141	0.661*	0.0788***	−0.0413***
	(0.0257)	(0.361)	(0.0283)	(0.0143)
Constant	−46.10***	15.1	−11.66***	−37.23***
	(7.182)	(21.93)	(1.619)	(6.657)
Wald Test	478.46	927.52	374.62	257.71
Prob. Value	0.0000	0.0000	0.0000	0.0000
Hansen J-statistics	7.12452	5.47728	10.1836	14.8269
Prob. Value	0.0076	0.0193	0.0014	0.0001
Wu–Hausman test	3.50892	0.55205	5.5546	0.708813
Prob. Value	0.4765	0.4575	0.0622	0.7016

The significant values of the Wald test statistics indicate that the models are correctly specified. The Wu-Hausman test statistic shows the potential presence of endogeneity, and the insignificant values of the Hansen J-statistics confirm the over-identifying restrictions. The robust standard errors are reported in parentheses. ***, ** & * indicate that the coefficients are significant at the 1%, 5%, and 10% levels, respectively

6 Conclusion and policy implications

In the contemporary context, the developing countries are striving to decouple environmental degradation from economic growth. Since the developing countries collectively account for almost two-thirds of global GHG emissions, it is critically important to identify the associated factors which influence the well-being of the environment in these countries without compromising their economic growth performances. Hence, in this study, we empirically investigated the linkages between globalization (economic, social, and political), human capital, and CO_2 emissions, controlling for several other macroeconomic variables, in the context of 78 developing economies from Asia, Africa, and LAC over the period from 1990 to 2016.

The results from the econometric analysis implicate that human capital development, across all three regions, inhibit CO_2 emissions in the developing nations of concern. On the other hand, economic globalization was found to boost CO_2 emissions for the developing nations altogether and also for the Asian countries considered in this study; while reducing the emissions for the LAC countries. Besides, social globalization was seen to homogeneously boost CO_2 emissions across the developing countries from all three regions. On the other hand, political globalization was witnessed to reduce CO_2 emissions overall as well as for the African and Asian countries. However, in the case of the LAC countries, political globalization was seen to slightly enhance the CO_2 emission levels. Furthermore, the findings revealed that human capital development and globalization (in all three forms) jointly exerted adverse environmental consequences by boosting CO_2 emissions.

These major findings contain relevant policy implications for policymakers, regulatory authorities, and governments of developing nations. First, it is pertinent to adopt policies that would enable the developing nations to develop their respective stock of human capital which, in turn, can be assumed to curb the emissions. Accordingly, both public and private expenditure on health and education should be scaled up significantly. Simultaneously, the governments should also incentivize private investors to invest in these human capital-developing sectors of the economy. Second, since globalization, particularly within the economic and social dimensions, was evidenced to degrade environmental quality, it is necessary for the associated governments to green their globalization policies. Precisely, these policies should not only be aimed at attaining high economic benefits but should also ideally work to negate the corresponding environmental hardships. Accordingly, the developing countries should adopt relevant policies against the inflows of dirty FDI; implementation of such policies would prevent these nations from not transforming in pollution heavens for foreign investors. Besides, the governments should also incentivize the local pollution-intensive export-oriented industries to employ cleaner fuels to mitigate the energy consumption-related GHG emissions.

Lastly, since the findings revealed that human capital development and globalization (in all three forms) jointly dampen environmental quality, it is of utmost relevance for the governments to make sure that globalization facilitates human capital development in developing countries. For instance, the governments should try to attract and redirect FDI towards the education and health sectors which would help to reduce the adverse environmental consequences associated with economic globalization via the channel of human capital development. Hence, it is recommended that similar interactive policies are adopted so that globalization does not neutralize the favorable environmental outcomes of human capital development across developing countries. Accordingly, it is important to augment the human capital development-enhancing policies within the globalization policies.

One limitation of this study is that we only used two composite indices of human capital development for predicting the human capital-CO_2 emissions nexus. Ideally, it would be interesting to explore the effects of different dimensions of human capital such as adult literacy, skilled labor, training, and enrollment in tertiary education on CO_2 emissions in order to compare the environmental impacts in conjunction with globalization. As far as the future direction of research, the reasons behind some of the puzzling findings such as political globalization reducing CO_2 emissions in Asia and Africa but increasing CO_2 emissions in the LAC region need to be further explored. Whether these dissimilar results suggest genuine and meaningful regional heterogeneity or not needs to be examined further. Furthermore, this study can also be replicated for a sample of developed countries for comparability purposes.

Appendix

See Table 8

Table 8 List of developing economies included in the study

Africa region	Asia region	LAC region
Algeria	Bahrain	Argentina
Angola	Bangladesh	Barbados
Benin	Brunei Darussalam	Bolivia
Botswana	China	Brazil
Burkina Faso	India	Chile
Burundi	Indonesia	Colombia
Cameroon	Iran	Costa Rica
Congo, Rep	Israel	Ecuador
Cote d'Ivoire	Jordan	El Salvador
Egypt, Arab Rep	Kuwait	Guatemala
Gabon	Malaysia	Haiti
Gambia, The	Myanmar	Honduras
Ghana	Nepal	Jamaica
Kenya	Pakistan	Mexico
Lesotho	Philippines	Nicaragua
Liberia	Qatar	Paraguay
Madagascar	Saudi Arabia	Peru
Malawi	Singapore	Uruguay
Mali	Sri Lanka	Venezuela, RB
Mauritius	Thailand	
Mauritius	Turkey	
Morocco	United Arab Emirates	
Mozambique	Vietnam	
Namibia		
Niger		
Nigeria		
Rwanda		
Senegal		
Sierra Leone		
South Africa		
Sudan		
Togo		
Tunisia		
Zambia		
Zimbabwe		

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