Different Dimensions of Globalization and CO2 Emission Nexus: Application of Environmental Kuznets Curve for Worldwide Perspective

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Abstract
This study investigates how various facets of globalization directly affect CO_2 emissions under the widely recognized Environmental Kuznets Curve (EKC) framework, utilizing panel data from a broad cross-section of countries. By incorporating economic, political, and social globalization indices alongside macroeconomic variables (GDP per capita, GDP growth, and manufacturing value added), this analysis furnishes a more holistic perspective on the overall globalization–environment nexus. The empirical strategy employs panel unit root tests to evaluate stationarity, followed by ordinary least squares and random effects to secure robust coefficient stability and extended-run insights. The findings validate an inverted U-shaped link between GDP per capita and CO_2 emissions, suggesting that while emissions initially climb with income in early development, they eventually decrease at higher income tiers, in line with the EKC hypothesis. Economic globalization typically shows a positive, albeit occasionally model-sensitive, association with emissions, implying that expanded trade and cross-border production can boost carbon output, particularly when technological or regulatory standards remain weak. In contrast, political and social globalization display weak or negligible direct impacts on CO_2 emissions, implying that diplomatic ties and cultural interactions alone may not fully suffice to curb pollution without complementary environmental measures. Interestingly, expansions in manufacturing value added often align with reduced emissions, underscoring the possible influence of cleaner industrial processes and efficiency improvements. These findings underscore the importance of policy initiatives that reconcile the benefits of global economic integration with rigorous environmental governance. Sustaining inclusive economic progress while mitigating environmental harm relies on constructing stronger institutional frameworks, leveraging targeted technological advances in manufacturing, and fostering global cooperation on emissions criteria.
Keywords: EKC, Economic Globalization, Political Globalization, Social Globalization
JEL Classifications: F60, F62, F64

1. INTRODUCTION

Rapid global warming and rising greenhouse gas emissions have propelled humanity to a critical juncture in the fight against climate change (Kumar, 2018; Ahmad, 2018; Klimenko et al., 2022; Nadeem et al., 2023; Audi et al., 2025). Numerous aspects of this persistent challenge have been thoroughly scrutinized within the domain of environmental economics, especially regarding the influential Environmental Kuznets Curve (EKC) hypothesis. The EKC states that although rising income eventually overturns this effect, enhancing environmental standards in affluent nations, economic expansion initially degrades ecological quality (Ali & Audi, 2016; William & Adam, 2018; Adejumo, 2020; Khalid & Abdul, 2025). Still, certain EKC dimensions—particularly given expanding global integration and diverse economic trajectories—remain comparatively scarcely explored overall. Recent econometric advances have spurred researchers to concentrate on specific domains and integrate additional variables, thereby expanding our understanding of environmental issues. Yet absent robust empirical frameworks, it remains distinctly difficult to determine how globalization specifically shapes carbon emissions, as global integration may either escalate or lessen pollution (Wang et al., 2019; Emodi, 2019; Nan et al., 2022; Al Rasasi, 2025). From several perspectives, globalization significantly amplifies ecological harm through manufacturing, large-scale transport operations, and ancillary effects tied to resource depletion and widespread deforestation.

Worsening environmental conditions magnify climate change repercussions and engender widespread crises, thereby jeopardizing socio-economic stability and ultimately affecting community welfare (Shahbaz et al., 2015; Ibrahim & Simian, 2023; Audi et al., 2024; Kumar & Wu, 2025). These outcomes highlight the need to thoroughly comprehend the multifaceted influences of globalization on ecosystems. Often, as global commerce expands, globalization traverses industrial production, transportation systems, and deforestation (Jean-Yves & Loïc, 2013; Calin & Horodnic, 2023; Ullah & Ali, 2024). It permits multinational enterprises to relocate manufacturing processes from developed to underdeveloped markets, thus exploiting cheaper labor and weaker ecological oversight (Ewing-Chow & Soh, 2009; Willy, 2018; Morgera, 2020; Ashiq et al., 2023; Zenios, 2024; Alvi & Mudassar, 2025). Although these transplanted industries can stimulate local economic growth, they often aggravate pollution where regulatory structures and environmental criteria are less stringent. The ongoing interplay between advanced and emerging economies also accelerates the cross-border sharing of policy expertise and cultural standards through globalization, spurring inclusive growth that addresses unemployment, poverty, and inequality. Meanwhile, global economic expansion necessitates heightened energy consumption, fueling intensified industrialization and urban expansion. Consequently, CO_2 emissions proliferate, eroding environmental quality and posing formidable sustainability challenges (Irfan, 2020; Ali et al., 2021; Awewomom et al., 2024; Sharma & Das, 2024; Hanvoravongchai & Paweenawat, 2025).

In recent decades, numerous studies have assessed how globalization affects CO_2 emissions, recording consistent patterns in time-series and panel datasets (Christmann & Taylor, 2001; Hassan & Sallh, 2020; Walsh, 2022). Evidence shows an enduring surge in global warming and climate volatility, with extensive social, economic, and ecological fallout. These include deforestation, rising sea levels, biodiversity loss, erratic wind patterns, altered precipitation or drought cycles, and widespread agricultural disruptions (Hawken et al., 2013; Vartiak, 2021). Such environmental instabilities have captured the urgent attention of researchers, policymakers, and governments worldwide (Panayotou, 1997; Weber, 2022; Jamel & Zhang, 2024; Al-Masri & Ibrahim, 2025). Discourse within the globalization–environment domain spans arguments lauding globalization's promotion of "green" technologies and those faulting it for displacing pollution-intensive industries to lower-income locales.

Supporters contend that globalization aids countries by reducing CO_2 emissions and fostering environmental stewardship (Christmann & Taylor, 2001; Shin, 2004; Achy & Lakhnati, 2019; James, 2020). Extensive trade networks and joint research initiatives under globalization stimulate the progression of sustainable technologies. They also encourage industrial innovation, cross-border capital mobility, and the dissemination of cleaner practices that may collectively mitigate global pollution. International supply chains, moreover, generate new products and manufacturing frameworks (Yeung & Coe, 2015; Wang & Chen, 2021; Yan & Sriboonchitta, 2024; Bozic & Bozic, 2025), while widespread information exchange heightens worldwide ecological awareness, inciting proactive efforts to safeguard the environment. Further, intense international competition impels firms to exceed ecological benchmarks to remain competitive. Multinational corporations are perceived as pivotal allies in mitigating global warming, given their subjection to strict environmental mandates in developed countries and their capacity to transfer eco-friendly know-how across national boundaries (Toth & Paskal, 2019; Montiel et al., 2021; Chen, 2021). Thus, pollution might plateau at an upper limit under "race to the bottom" dynamics, since globalization magnifies public vigilance (Dasgupta et al., 2002; Mustapha, 2022).

Critics, however, argue that globalization compromises environmental well-being by intensifying CO_2 emissions (Copeland & Taylor, 2004; Aichele & Felbermayr, 2013; Shahbaz et al., 2015). They maintain that growing economic activities, lacking sustainable production and consumption transitions, burden ecosystems. While globalization does spur growth, notably in lower-income regions, it can also exacerbate resource depletion and parallel forms of environmental damage if robust protective frameworks are missing (Wijen & Van Tulder, 2011; William, 2021; Ahmed & Alvi, 2024). In line with this perspective, Panayotou (1997) asserts that newly industrializing and developing nations now endure heavier pollution levels than four decades earlier, particularly relative to advanced economies. This stance underscores the ambiguity tied to the globalization–environment axis, as wealthier countries express disquiet over "dirty" sectors proliferating in emerging markets, where these activities progress at the expense of ecological equilibrium. Current conclusions from the World Resources Institute's Climate Data Explorer underscore these patterns. Outcomes of this nature often arise from shifts in open-market regimes (Baek et al., 2009; Panayotou, 1997). In low-income contexts, lax regulation and inadequate adherence among high-polluting businesses further deteriorate environmental conditions. Consequently, globalization can motivate the relocation of such industries to jurisdictions with lax policies, allowing affluent economies to uphold ecological standards via stricter governance (Copeland & Taylor, 2004). Dreher's (2006) globalization index has proven especially valuable, breaking globalization into economic, political, and social dimensions, thereby offering deeper insights into carbon emission trends.

Economic globalization involves merging national economies into the broader global setting through trade liberalization, cross-border investments, and open capital flows. Many inquiries have evaluated its ramifications for carbon outputs, typically pointing out both the beneficial and detrimental implications of growing economic interdependence. Relaxed trade and investment regimes accelerate the adoption of modern clean-production technologies and environmentally friendly practices. Nonetheless, certain regions with looser ecological standards may welcome pollution-intensive industries, mirroring the core of the "Pollution Haven Hypothesis," wherein corporations relocate to places with weaker rules. Gauging national and global market integration commonly relies on indices capturing trade intensity, trade barriers, tariff policies, and capital controls (Skhirtladze & Nurboja, 2019; Raza & Lin, 2020). This helps determine whether economic globalization triggers a race-to-the-bottom pattern of environmental policies or drives a race-to-the-top outcome through competition and knowledge exchange, as postulated in the "Porter Hypothesis."

Political globalization entails a nation's involvement in global policymaking arenas and adherence to unified standards and protocols. This facet encompasses the number of embassies, engagements in regional or international bodies, and memberships in prominent institutions like the UN Security Council or other major global pacts (Marks & Hooghe, 2003). Such political connectedness can facilitate collective environmental accords, reinforcing cohesive governance structures worldwide aimed at cutting carbon emissions (Biermann & Siebenhüner, 2009). Under these frameworks, states jointly address ecological challenges, co-develop anti-pollution technology, and maintain elevated environmental goals (Bhagwati, 2004). Paramati et al. (2017) determine that greater political globalization correlates inversely with carbon outputs, implying that diplomatic cooperation and consensus may foster better environmental outcomes. Indeed, political globalization bolsters collective responsibility, policy transparency, and more stringent monitoring and enforcement of ecological protocols.

Social globalization involves all elements of human connections beyond borders, cultural assimilation, and cross-border information flows. Certain researchers measure social globalization through international travel flows, digital communication penetration, and other cultural variables (Song et al., 2018). A prevailing assumption is that expanded connectivity disseminates environmental knowledge and sustainable practices worldwide. Based on World Society Theory, universal norms such as conservation ethics and climate activism are transmitted via educational institutions, global civil society links, and media outlets. Hartmann and Vachon (2018) contend that heightened exposure to ecological issues fuels grassroots mobilization and consumer pressure, driving governments and businesses toward stricter emissions cuts. Equally, intense cross-national collaboration and information sharing due to higher social interconnectivity can expedite better policy enactments (Liu et al., 2015; Willy, 2018). As societies learn of carbon-optimized approaches in other regions, they tend to replicate these practices for collective emissions reduction gains.

2. LITERATURE REVIEW

From the late 1980s onward, greenhouse gas emissions have risen in prominence among economists and policymakers. Consequently, a body of research has focused on the interplay between economic growth and emissions. Several studies cite an inverted-U pattern supporting the EKC (Galeotti et al., 2006; Heil and Selden, 2001), whereas others indicate an N-shaped trend marked by renewed increases in emissions (Fried and Getzner, 2003). The debate continues, however, as some scholars question EKC's broader applicability (Spangenberg, 2001). More recent works provide evidence affirming the EKC in specific contexts. For instance, Shahbaz et al. (2013) observed that when energy consumption was integrated into models of CO_2 emissions, an EKC structure emerged in Romania. Tiwari et al. (2013) found a parallel pattern in India, while Junyi (2006) documented a similar occurrence across Chinese provinces. Overall, the variability of EKC behavior across nations and regions underscores the need for more extensive approaches to studying how growth intersects with greenhouse gas outputs. Such findings highlight the tight linkage between development and ecological impacts.

Building on earlier inquiries, globalization can serve as an engine for economic progress, advancing technology transfer, labor specialization, and novel investment avenues. Researchers have investigated trade, capital movements, and investments relative to greenhouse gas outputs. Grossman and Krueger (1991) point out that trade liberalization can influence ecological outcomes through scale effects, whereas Copeland and Taylor (2004) propose that factor endowments, trade levels, and regulatory frameworks shape trade's net environmental repercussions. Some studies suggest that trade liberalization fosters ecological gains by facilitating technological advancement (Antweiler et al., 2001). Contrary views, however, endure. Dean (2002) found that trade liberalization harmed environmental quality in China.

Trade liberalization can enable governments, especially those endowed with substantial fiscal capacity, to import cleaner technologies and enact sustainable, inclusive growth. Research nonetheless notes a dynamic wherein openness favors short-run growth in emerging countries but compromises ecological health. This detrimental pattern is less frequent in advanced economies yet recurs in developing regions (Christmann & Taylor, 2001; Copeland & Taylor, 2004). As posited by the pollution-haven argument, pollution-heavy industries relocate from wealthier locations—where environmental controls are rigorous—toward less stringent jurisdictions. Such a shift lowers production costs but intensifies local pollution. These enterprises frequently manufacture goods for export to wealthier nations, allowing the latter to maintain cleaner environments and higher living standards while placing environmental burdens on lower-income areas. Such arrangements adversely affect ecosystems and human livelihoods. Cross-border problems like ozone depletion, global warming, climate volatility, deforestation, and acid rain reach beyond national boundaries, impacting all regions. Therefore, both rich and poor nations contribute to current environmental dilemmas. Prosperous economies cannot preserve high living standards without confronting global warming, and the industrialization achieved via multinational investments in developing states often remains ecologically taxing (Taylor & Copeland, 2003). Likewise, additional sources (Schmalensee et al., 1998; Chaudhuri & Pfaff, 2002; Ling et al., 2015) contend that global trade hastens resource exhaustion, spurs greater CO2 emissions, and undermines environmental standards in both industrialized and emerging contexts.

Contemporary research notes that globalization significantly factors into today's environmental degradation. Chakraborty and Mukherjee (2020) hold that globalization harms the environment as greater trade openness increases pollution levels globally. Similarly, Yang et al. (2020) observe that globalization diminishes environmental well-being by spurring economic expansion and industrialization. Notwithstanding abundant scholarship on globalization and ecological health, the linkage remains intricate and contradictory. Certain inquiries posit that globalization may yield environmental benefits, whereas others underscore its detrimental effects, leaving policymakers conflicted about methods to mitigate these issues. Drawing on WIOD datasets for 40 economies, Löschel et al. (2013) discovered that expanded trade elevates energy intensity and CO2 emissions, thereby degrading environmental quality. Likewise, Kanjilal and Ghosh (2013) revealed that trade openness in India lowered CO2 emissions, thus enhancing environmental conditions. By contrast, Paramati et al. (2017) emphasized how political globalization can reduce carbon outputs and safeguard ecological integrity. Shahbaz et al. (2017) incorporated economic, social, and political globalization into an augmented emissions model for China, identifying a long-run interdependence among the variables and determining that globalization yields a positive environmental effect. They further noted one-way causality from globalization to CO2 emissions, suggesting that global engagement drives shifts in emission trajectories. Although many studies rely on trade openness as a narrowed proxy for globalization in analyzing its ties to CO2 emissions, the benefits in some cases can be offset by negative outcomes in others. Given divergent findings, a broader globalization index such as Dreher's (2006), encompassing economic, political, and social components, is warranted.

The BRICS economies, by their nature, have witnessed how globalization provides both advantages and obstacles. It has stimulated trade, growth, and investment alongside mounting environmental strains. Accordingly, in promoting clean energy and mitigating pollution, BRICS governments have implemented several initiatives. Wang et al. (2023) discerned that trade liberalization heightened Chinese CO2 emissions, while Li et al. (2023) determined that globalization worsened environmental quality. Moreover, Zhang et al. (2022) reported that foreign direct investment amplified greenhouse gas emissions in China, though Peng et al. (2023) argued that FDI spurred growth coupled with ecological enhancement. Such conflicting results validate the need for a holistic plan in addressing globalization's diverse environmental influences.

Policymakers in BRICS should align policies to dampen globalization's negative implications while maintaining economic progress. In doing so, these nations can pursue ecological management goals consistent with sustained development, balancing environmental safeguards and growth imperatives.
Most EKC studies primarily address economic growth and trade liberalization as significant drivers of CO_2 emissions (Grossman & Krueger, 1991; Copeland & Taylor, 2004; Shahbaz et al., 2013). Though numerous works corroborate the EKC in multiple nations (Apergis & Payne, 2009; Martínez-Zarzoso & Bengochea-Morancho, 2004; Tamazian et al., 2009; Altaf & Shahzad, 2021), the argument frequently simplifies matters by treating trade openness as the lone gauge of globalization, omitting its political and social features (Antweiler et al., 2001; Baek & Kim, 2013; Karhan, 2019). Further, most such analyses rely on data from a single nation (Lean & Smyth, 2010; Acaravci & Ozturk, 2010) or a handful of countries, limiting their applicability to broader policymaking. Some recent research has broadened the scope by incorporating alternative globalization measures (Paramati et al., 2017; Avelino & Coronel, 2021), yet geographic coverage typically remains limited to areas like China or India, and results do not definitively elucidate globalization's overall ecological consequences. Another pressing consideration is the necessity for a global-level investigation incorporating all dimensions of globalization—economic, social, and political—within an EKC framework to clarify how CO2 emissions behave. This paper aims to address that gap across a longer timeframe and by using a more all-encompassing globalization index, thereby providing more wide-ranging policy insights into forging a sustainable equilibrium between economic advancement and environmental conservation. Rather than relying solely on trade or foreign investment as indicators of global interconnectedness, this analysis evaluates multiple pathways for globalization's emergence, offering a deeper understanding of its capacity to either exacerbate or mitigate environmental harm in varying contexts. By resolving the identified empirical shortfalls, the present study delivers policy-related evidence that can assist authorities in shaping international environmental agreements and appraising globalization-driven ecological repercussions.

3. THEORETICAL FOUNDATIONS AND EMPIRICAL MODEL

Before examining the methodological approach of this study, it is vital to understand how globalization influences the scale and trajectory of carbon emissions across both developed and developing markets. Globalization is frequently regarded as a modern economic mechanism that promotes growth and welfare by easing trade and investment barriers (Collier & Dollar, 2002). However, opinions differ, with some arguing that globalization influences carbon emissions and economic activities through multiple channels. When a nation participates in global trade and financial flows, the demand for energy in producing goods and services grows, thereby inevitably raising its overall carbon footprint. For instance, the Pollution Haven Hypothesis underscores the potential for significant negative emission impacts (Taylor, 2005). On the other hand, globalization can bolster environmental well-being by curtailing carbon outputs through the exchange of technological know-how and expertise. Multinational enterprises leveraging cleaner technology may thus attain higher economic growth while moderating energy use, and preserving ecological quality. Trade, investment, and innovation shape environmental conditions and production processes. First, persistently elevated CO2 emissions will inevitably degrade ecological standards. Second, the severity of such degradation depends on production technology choices. Firms relying on polluting, energy-intensive strategies might stimulate economic gains, yet these approaches exacerbate environmental harm, fueling climate change and global warming. In particular, the Porter Hypothesis maintains that more stringent regulations can spur cleaner, more efficient production methods (Wagner, 2003).

Globalization influences carbon emissions via numerous pathways, linking nations economically and financially. As an economy expands, its energy requirements escalate, generally driving up carbon outputs. Social globalization, through interpersonal networks, information diffusion, and cultural exchange, cultivates knowledge about environmental management, thereby reducing energy use across sectors and preserving ecological stability. Meanwhile, political globalization involves elements such as embassies and treaty participation, reinforcing global environmental governance. Under these conditions, robust policy implementation and international coordination can direct globalization's facets to modulate carbon footprints across various states. According to Tamazian and Rao (2010), institutions fortified by global integration can significantly upgrade environmental outcomes by enforcing strict rules. A scale effect surfaces when trade openness fosters economic expansion, heightening energy consumption and worsening environmental degradation, particularly in the early EKC phases. In emerging markets, globalization routinely erodes ecological integrity during industrial takeoff. Businesses failing to innovate with low-energy inputs or to comply with rigorous standards often privilege profit over sustainability, raising carbon emissions. Moreover, absent a collective cultural shift toward environmentally responsible norms, the broader globalized framework may continue weakening ecological safeguards. Still, openness and structural transitions in production enable globalization to mitigate environmental stresses. When firms in developing locales adopt imported, energy-efficient innovations, globalization can move output away from energy-heavy sectors toward more service-based activities (Willy, 2018; Keramidas et al., 2021). By capitalizing on advanced economies' hybrid solutions, emerging nations can trim energy usage and enhance environmental standards through deeper trade integration.

Determining whether distinct globalization dimensions and carbon emissions follow a U-shaped or inverted U-shaped pattern constitutes the central research inquiry of this study, drawing on World Bank data for 1970–2023. The general carbon emission function is:

$$CO_{2it} = f(G_{it}) \quad (1)$$

The empirical model's equations then become:

$$CO_{2it} = \alpha_0 + \alpha_1 EG_{it} + \alpha_2 YPC_{it} + \alpha_3 YPC^2_{it} + \alpha_4 MFG_{it} + \alpha_5 PG_{it} + \alpha_6 SG_{it} + u_{it} \quad (2)$$

$$CO_{2it} = \beta_0 + \beta_1 EG_{it} + \beta_2 EG^2_{it} + \beta_3 YPC_{it} + \beta_4 YPC^2_{it} + \beta_5 MFG_{it} + \beta_6 PG_{it} + \beta_7 SG_{it} + v_{it} \quad (3)$$

$$CO_{2it}=\gamma_0+\gamma_1 EG_{it}+\gamma_2 EG^2_{it}+\gamma_3 YPC_{it}+\gamma_4 YPC^2_{it}+\gamma_5 Yg+\gamma_6 Yg^2+\gamma_7 MFG_{it}+\gamma_8 PG_{it}+\gamma_9 SG_{it}+\varepsilon_{it} \quad (4)$$

where α_i, β_i, γ_i are the estimated parameters, u_i, v_i, ε_i are the white noise error terms.

Detailed variable definitions, measurement methods, and data sources are presented in Table 1.

Table 1: Variable and Data Sources

Variables	Definition	Sources
CO2	CO2 emissions (metric tons per capita)	World Development Indicators (WDI)
Yg	GDP growth rate	World Development Indicators (WDI)
Yg^2	GDP growth rate squares term	World Development Indicators (WDI)
YPC	GDP per capita (Current US dollars)	World Development Indicators (WDI)
YPC^2	GDP per capita squares term	World Development Indicators (WDI)
MFG	Manufacturing, value added (annual % growth) as a proxy for different types of energy use in manufacturing	World Development Indicators (WDI)
Eg	Economic globalization Index	KOF Swiss Economic Institute
Eg^2	Economic globalization squares term	KOF Swiss Economic Institute

Pg	Political globalization Index	KOF Swiss Economic Institute
Sg	Social globalization Index	KOF Swiss Economic Institute

4. ECONOMETRIC METHODOLOGIES

Using econometric methods has become integral to applied economics and other management sciences. In this study, various panel unit root tests—specifically Levin, Lin, and Chu (LLC) (2002), Im, Pesaran, and Shin (IPS) (2003), Breitung (2001), and Maddala and Wu (1999)—are employed to assess the stationarity properties of the variables. A variety of approaches then evaluates how regressors influence the regressed, including panel ordinary least squares and random effects models, ensuring a robust empirical framework and consistency.

5. RESULTS AND DISCUSSION

The descriptive statistics from Table 2 reveal substantial dispersion across the analyzed variables, with numerous indicators displaying pronounced skewness and kurtosis. Carbon emissions, for instance, exhibit a distribution dominated by high values concentrated in a few countries, consistent with evidence that a limited number of economies contribute disproportionately to global carbon output. GDP growth likewise indicates considerable dispersion, implying that some observations diverge sharply from average development patterns. These outliers could be genuine economic shocks or potential data anomalies, highlighting the necessity for robust estimation strategies in future research. GDP per capita likewise manifests a skewed distribution, driven upwards by a few wealthy nations, emphasizing ongoing global income disparities. Manufacturing growth rates further vary extensively, pointing to region-specific elements such as policy frameworks, resource endowments, and market access. Such trends indicate that transformations (e.g., log transformations) or the trimming of outliers may be advantageous to mitigate extreme values' influence on parameter estimates. On the other hand, the globalization indices—economic, political, and social—exhibit more symmetric distributions, moderate variance, and reduced skewness. This suggests that while some nations exhibit very high global integration, a considerable proportion remain in a mid-range category of cross-border connections. Overall, these descriptive statistics reinforce the importance of careful data management, particularly for skewed variables, to ensure credible empirical insights into the drivers and outcomes of carbon emissions.

Table 2: Descriptive Statistics

Variables	CO2	Yg	YPC	MFG	EG	PG	SG
Mean	3.994	53.571	1033848.	1.5938	51.56210	53.97984	51.251
Median	2.075	3.8026	23408.29	3.6492	50.66624	54.69917	50.979
Maximum	49.30	20320.0	2.3408	6.2610	92.77380	97.97477	92.19900
Minimum	-13.36	-64.047	-7.226150	-80.074	12.53501	2.958512	4.5874
Std. Dev.	4.723	874.81	7145655.	2.6129	16.55212	24.72946	21.682
Skewness	2.003	18.602	19.25542	21.381	0.212999	-0.115284	-0.1025
Kurtosis	9.682	362.66	478.4513	475.86	2.498641	2.030058	1.9308
Sum	20341.6	272837.3	5.2709	8.1011	262605.8	274919.3	261021.5
Sum Sq. Dev.	113598.2	3.9009	2.6017	3.46E+22	1395069.	3113993.	2393880.
Observations	5131	5131	5131	5131	5131	5131	5131

The correlation analysis from Table 3 highlights certain noteworthy interconnections among variables, while many remain only weakly linked. The strongest correlation emerges between GDP growth and manufacturing value added, supporting the notion that industrial activity can serve as a key driver of overall economic expansion (Rodrik, 2006). Economic and social globalization are likewise substantially interrelated, aligning with arguments that economic liberalization encourages cross-border cultural engagement and idea exchange (Martinez, 2002). Meanwhile, the weaker correlation for political globalization suggests that diplomatic participation in international institutions does not necessarily advance at the same pace as social or economic dimensions (Kobrin, 1997). Carbon emissions show mild positive correlations with most variables, consistent with the premise that determinants beyond basic income or trade, such as energy frameworks, technological choices, and environmental regulations, often shape emissions trajectories (Milindi & Inglesi-Lotz, 2022). The near-zero relationship between carbon emissions and GDP growth indicates that short-term economic gains do not invariably boost or curb emissions proportionately, reinforcing claims that structural and technological pathways play key roles in the growth-emissions nexus (Du et al., 2023). This correlation overview underscores manufacturing's primary role in driving economic expansion, the interconnectedness of economic and social facets of globalization, and the multifaceted influences on carbon emissions.

Table 3: Correlation Matrix

Variables	CO2	Yg	YPC	MFG	EG	PG	SG
CO2	1						
Yg	-0.0016	1					
YPC	0.03531	-0.0082	1				
MFG	0.01109	0.92542	-0.0087	1			
EG	0.1682	0.00486	0.14300	0.0065	1		
PG	0.05322	0.0341	0.07367	0.0097	0.3430	1	
SG	0.23639	0.0129	0.13521	0.0316	0.8157	0.31233	1

The panel unit root tests (table 4) highlight the importance of testing for stationarity in panel data. At levels, GDP growth and manufacturing value added exhibit stationarity, but other variables, including carbon emissions, GDP per capita, and globalization indices, often fail to reject the null of non-stationarity in some tests. Carbon emissions, for example, appear non-stationary under most tests but are deemed stationary by Fisher ADF and PP, indicating inconsistent results. GDP per capita mostly remains non-stationary until differenced, fitting broader findings that underscore non-stationarity in many income variables. Economic and political globalization also present mixed outcomes, suggesting that different integration pathways can affect their time-series behavior. Differencing resolves stationarity concerns across all variables, confirming that first differences adequately address potential unit roots. This is especially critical for GDP per capita and social globalization, both of which consistently fail stationarity at levels but pass once differenced. These observations reinforce the standard practice of carefully determining each variable's integration order to avoid spurious regression. The broad stationarity achieved via differencing implies that subsequent analyses, whether cointegration methods or differenced estimations, will yield more valid conclusions. Overall, the need to transform certain macroeconomic and globalization measures underscores the necessity of rigorous procedures for ensuring robust panel estimations.

Table 4: Results of Panel Unit Root

Variables	LLI	IPS	Bruiting	Fisher ADF	Fisher PP
Test statistics at levels					
CO2	-0.594	-1.558	8.691	670.9***	686.4***
Yg	-27.22***	-50.41***	2.123	3164.9***	3414.7***
YPC	78.542	86.831	-15.40***	95.141	104.1
MFG	-33.08***	-47.58***	78.70	2801.7***	2942.4***
EG	-7.322***	1.9426	-27.36***	396.6	406.7
PG	-9.008***	2.7555	2.234	477.9	565.0
SG	22.20	34.853	17.72	63.55	68.81
First difference test statistics					
CO2	-84.87***	-81.89***	-46.04***	5124.8***	5697.7***
Yg	-119.8***	-116.5***	-55.68***	6874.4***	6850.3***
YPC	-20.45***	-33.37***	-51.05***	2297.4***	2320.7***
MFG	-107.1***	-97.98***	13.487***	5366.9***	6969.5***
EG	-82.66***	-77.54***	-5.912***	5148.6***	5308.8***
PG	-85.74***	-80.52***	-57.98***	5427.2***	5598.9***
SG	-64.90***	-66.27***	-41.43***	4381.2***	4483.8***

Note: Note: 1) LLC, Breitung, and IPS represent the panel unit root tests of Levin et al. (2002), Breitung (2000) Im Pesaran and Shin (2003), respectively. Fisher-ADF and Fisher-PP represent the Maddala and Wu (1999) Fisher-ADF and Fisher-PP panel unit root tests, respectively. *** Statically significance at 1% level.

The empirical findings of table 5 provide perspective on Models 1, 2, and 3, revealing both shared patterns in how key predictors influence carbon emissions and important differences that emerge as new variables and specifications are introduced. Each model examines emissions as the dependent variable, yet they differ in terms of explanatory variables, modeling approaches (panel OLS versus random effects), and the handling of non-linearities and unobserved heterogeneity. Model 1 focuses on economic globalization, GDP per capita (and its square), manufacturing value-added, and political and social globalization. Model 2 introduces the same core set of variables but refines how economic globalization is measured and highlights subtle shifts in manufacturing's effect, while also reinforcing certain findings about GDP per capita. Model 3 incorporates the GDP growth rate and its squared term, adding another layer of complexity to the assessment of how economic expansion affects environmental outcomes.

The results of Model 1 indicate a significant positive impact of economic globalization on carbon emissions across both the panel OLS and random effects models. Coefficients of 0.014 and 0.0151, respectively, explain that deeper economic integration—manifested through expanded trade, foreign direct investment, and global value chains—correlates with higher levels of carbon dioxide emissions. This pattern is consistent with the "scale effect," in which increased production volumes to meet external demand can amplify energy consumption and environmental stress, particularly if fossil fuels remain the primary energy source (Ahmad, 2018; Yi et al., 2023). A relevant theoretical framework that sheds light on these findings is the environmental Kuznets curve hypothesis, which posits that environmental degradation initially worsens during the early stages of economic development but eventually diminishes after an economy surpasses a certain income threshold (William & Adam, 2018; Acheampong & Opoku, 2023). While advanced economies may be better equipped to adopt cleaner technologies, the positive and significant coefficients for economic globalization in this analysis show that any "turning point" envisioned by the

EKC may be delayed or weakened without strong institutional structures and policy interventions (Ashford et al., 2011; Emodi, 2019; Ibrahim & Simian, 2023). In effect, the pace at which industries integrate and expand through global markets can outstrip the adoption of greener processes, perpetuating higher levels of carbon emissions in many developing or newly industrializing regions. Research indicates that countries experiencing strong economic globalization often sustain competitiveness through an energy-intensive industry that contributes to pollution (Hussain & Zhou, 2022; Calin & Horodnic, 2023; Ullah & Ali, 2024). According to Copeland and Taylor (2004), global trade liberalization itself may alter a country's production structure, referred to as the "composition effect," away from producing less-polluted goods to more pollution-intensive outputs in cases where the environmental regulations are not stringent.

Similarly, Zhang et al. (2022) have found that while economic globalization can facilitate the transfer of clean technologies, there could still be net negatives on account of emissions unless some specific policy instruments become operational for promoting production-clean-technology. These patterns can be explained well by the so-called pollution haven hypothesis, which states that industries with large pollution potentials could migrate to countries with poor environmental regulations, allowing local emissions to rise (Levinson, 1996; Willy, 2018; Zenios, 2024). This explanation is also consistent with the regression results that show greater coefficients, suggesting potential relocation of carbon-intensive production for cost-saving purposes. Further empirical evidence elucidates the complexity underlying this relationship, stating that there could be an avenue for reducing emissions due to economic globalization through the transmission of cleaner technology (Söderholm, 2020; Sharma & Das, 2024). However, in many cases, the pace of adopting eco-friendly practices appears slow compared to the rapid increase in cross-border economic activities (Bleischwitz et al., 2009; Irfan, 2020). Liu et al. (2015) point out that without complementary measures, the benefits of global economic integration—such as job creation, technology transfer, and economic diversification—often come with an environmental trade-off.

The findings of Model 1 show that GDP per capita exerts a statistically significant and positive influence on carbon emissions in both the panel OLS and random effects models, with a coefficient of 6.11. This result shows that higher income levels are associated with increased energy consumption, often relying on carbon-intensive fuels, ultimately leading to greater per capita emissions (Davis & Caldeira, 2010). Such a trend is often seen where generally more growth entails more production, more consumption, and more construction, thus impacting emissions. The negative, significant coefficient of squared terms of GDP per capita, which stands at -2.18, reflects that the turning point in the relationship comes at increased incomes. This adds credibility to the observation of the environmental Kuznets curve hypothesis, which shows a relationship in an inverted-U shape between pollution and economic development. In all these factors, to start with, pollution rises with economic growth, but with time, stabilization or decline sets in once a certain level of income is attained—all these within the EKC framework. Such an income shift generally comes along with a structural change in the economy, stronger environmental laws, and cleaner technologies. Evidence exists which suggests that high-income countries do get into less-polluting industries and spend more on environmental protection, which can help counteract earlier rises in emissions (Hilson, 2000; Hassan & Salha, 2020; Walsh, 2022). In agreement, the negative sign on the squared term in this study suggests that after attaining a certain level of wealth, further increases in GDP per capita bring less marginal impact on emissions (Li & Lin, 2013; Vartiak, 2021; Weber, 2022). Nevertheless, the extent of this turning point and the rate at which the economies transit to greener pathways can vary widely based on factors like institutional quality, technological capacity, and political will.

The coefficients measured in Model 1 find a negative and significant association between carbon emissions and manufacturing value-added, with the coefficient being -7.37 in the arrangements of random effects and panel OLS. Hence, an increase in manufacturing value added may be associated with a reduction in carbon emissions, versus the widely held notion that manufacturing with high energy intensity causes emissions in the past and present. One possible explanation could be the sustained structural changes that are being set on manufacturing activities in many economies toward energy efficiency and reducing carbon intensity (Cadez & Guilding, 2017; Jamel & Zhang, 2024). When more advanced technologies come into use, coupled with tighter regulations, industries tend to adopt cleaner production processes that contribute toward reduced emissions and, at the same time, add to their value resource base. Some studies reveal that gaining manufacturing efficacy can bring about tremendous reductions in carbon emissions in both developing and advanced economies (Wang et al., 2019; Achy & Lakhnati, 2019; James, 2020). Such improvements are sometimes engendered by the switch to higher value-added sectors, such as advanced manufacturing and specialized technology, which implicitly should consume less energy in comparison with traditional heavy industry. In addition, many empirical studies have confirmed the working of technological innovations, specifying that new production processes usually operate with contemporary energy sources and machinery, in return ensuing lower emission intensity in manufacturing (James, 2020; Bai et al., 2021; Wang & Chen, 2021).

Furthermore, the demand for global standards and systems for environmental certification may be causing a negative coefficient through the pressure on manufacturing companies to modify their processes to embrace environmentally friendly protocols. This corresponds to the research suggesting that multinational firms and exporters are coming under increasing pressure from the international market to meet sustainability standards, thereby inducing the manufacturing sector in adopting greener practices (Nunes et al., 2010; Yan & Sriboonchitta, 2024). The outcome also corroborates the general literature on decoupling whereby an economy can still enjoy industrial growth while shrinking its energy-related carbon emissions footprint (Mustapha, 2022; Zhou et al., 2024). Over time, as manufacturing sectors modernize, a growing share of industrial output may be generated through cleaner techniques, reflecting a deliberate move away from emission-intensive operations. While this trend does not universally apply, some regions still rely heavily on fossil fuels for industrial expansion, the overall negative coefficient signifies a potential shift toward more sustainable manufacturing pathways, underscoring the importance of technological advancement and stringent environmental regulations in driving lower emissions intensity (Toth & Paskal, 2019; Chen, 2021; William, 2021).

The estimation results explain that political globalization exhibits a weak and insignificant relationship with carbon emissions. The coefficients of 0.0065 under panel OLS and 0.0015 under the random effects model fail to indicate a strong linkage. This shows that while political ties and international agreements can lay the groundwork for collaborative environmental governance, they do not necessarily translate into immediate or uniform emissions reductions unless accompanied by concrete policy enforcement and technological support. Political globalization may also require substantial time lags before any tangible environmental impact becomes evident (Kutting, 2004; Ahmed & Alvi, 2024). This kind of weak or insignificant effect is usually seen in social globalization, which consists of cultural and social interactions plus the flow of ideas across borders (Ellis, 2011; Skhirtladze & Nurboja, 2019). Social globalization advocates environmental consciousness and builds a norm of global sustainability, although not so much manifestly different behavior or advocacy in consumers contesting green that would achieve a reduction of carbon emissions in the short run. Some studies suggest that awareness at the society level should be coupled with targets of specific economic and technological intervention such as the use of clean energy and resource-efficient practices in order to attain meaningful reductions in emissions (Willy, 2018; Falcone, 2023).

The estimates for economic globalization in Model 2 provide a comprehensive insight into the tie that the aforementioned phenomenon has to carbon emissions. Using the panel OLS approach, economic globalization shows a coefficient of 0.027, but the mean is not statistically significant. On the contrary, the random effects model gives a coefficient of 0.01, which is statistically significant. This divergence in statistical significance as a consequence underlines the model specification and handling of unobserved heterogeneity across countries or regions. Random effects techniques account for time-invariant characteristics that may vary across units, potentially yielding different inferences about the effect of globalization on emissions. In practical terms, the positive coefficient especially when significant explains that greater integration into the global economy can correspond with higher levels of carbon emissions, often attributed to intensified production, trade, and transportation requirements (Avetisyan, 2018; Altaf & Shahzad, 2021). Nevertheless, the lack of significance in the panel OLS model indicates that this relationship is not always robust and could be confounded by other factors, such as specific domestic policies or regional differences in technology adoption.

One explanation for these mixed results lies in the possibility that some economies achieve globalization through sectors less reliant on carbon-intensive fuels. For instance, if a country's globalization strategy heavily emphasizes services, digital platforms, or high-technology exports, its carbon footprint might not increase to the same extent as in nations specializing in pollution-intensive manufacturing (Karhan, 2019; Demiral & Demiral, 2023). Additionally, countries at different stages of economic development might show distinct responses to globalization. Emerging economies often rely more on fossil fuel-based energy systems, potentially reinforcing the link between globalization and emissions. Meanwhile, advanced economies can invest in cleaner energy alternatives and environmental regulations, thereby weakening this linkage. This duality can lead to differences in how economic globalization's impact manifests across a diverse panel data set, resulting in variations depending on the estimation technique employed.

In Model 2, GDP per capita remains positive and significant at 5.98 in both the panel OLS and random effects models. The consistency across methodologies suggests a robust positive correlation between rising income levels and carbon emissions. A higher income typically translates into greater energy consumption through expanded industrial output, increased household consumption of goods and services, and the proliferation of private vehicles (Avelino & Coronel, 2021; Yosritzal et al., 2024). As nations become wealthier, infrastructure construction and commercial activities often intensify, thereby increasing fossil fuel combustion and emissions outputs. These broad patterns have been observed in cross-country empirical studies, where per capita income reliably serves as a strong predictor of environmental pressure. However, the results also show that the squared term of GDP per capita has a statistically significant negative coefficient of -2.16 in both models. This negative sign on the squared income term supports a non-linear pattern akin to the environmental Kuznets curve hypothesis, which explains that pollution levels initially rise with income but gradually recede after surpassing a certain threshold of economic development. In essence, as per capita income grows, societies may invest more heavily in cleaner technologies, enforce stricter environmental regulations, and shift to service-oriented economic structures, all of which help mitigate emissions.

Another notable finding pertains to manufacturing value-added, which exhibits a significant negative relationship with carbon emissions, with a coefficient of -7.27 in both the panel OLS and random effects estimates. Hence, manufacturing value addition rises with a decline in emissions, which clearly could be seen contrary to the orthodox views concerning the industrial sector's impacts on sustainability. Here, however, it might stand well in terms of transformation and technology upgradation in the manufacturing sector. Countries around the globe have been increasingly adopting cleaner and more efficient production methods, including lean manufacturing, energy-saving machines, and utilizing renewable energy sources (Klemeš et al., 2019), in the last few decades. Such measures can lower the carbon intensity of manufacturing which could thus mean there could be an increase in value added and a reduction in emissions.

The coefficients for political globalization and social globalization do not exhibit strength and statistical significance in both panel OLS and random effects analyses, with scores of 0.003 and 0.004 respectively. Certainly, political globalization should cover alliances or agreements between countries at least concerning improving environmental cooperation; however, their linkages with emissions might not be immediately discernable. Cross-border political collaboration often requires protracted negotiations and may be limited by divergent national interests, economic pressures, and mismatched regulatory frameworks. Thus, while international treaties and coalitions can set ambitious climate targets, they may not automatically translate into direct, measurable reductions in carbon emissions in the short run. Likewise, social globalization, which encompasses information exchange, cultural diffusion, and interpersonal connections across borders, may shape environmental awareness and norms over longer time horizons. However, the immediate effect on emissions appears relatively muted, as evidenced by the small coefficients in this analysis. Shifts in social consciousness, consumer preferences, and global cultural attitudes can indeed influence environmental policy and practice, but these shifts may require sustained effort and policy alignment to yield substantial emissions reductions (Webb, 2012). For instance, a rise in eco-conscious consumer behavior could theoretically encourage green production and reduce carbon footprints, but the scope and speed of such transformations vary widely across different societies and industries.

The panel regression results for Model 3 explain that economic globalization retains a positive association with carbon emissions, although its effect varies by estimation technique. In the random effects analysis, the coefficient of 0.014 is statistically significant, implying that economies deeply integrated into global markets through trade, capital flows, and cross-border production chains tend to record higher carbon emissions. By contrast, the panel OLS result of 0.0113 is insignificant, indicating that model-specific assumptions about unobserved heterogeneity can alter the strength of the estimated impact. Such discrepancies highlight that structural differences across countries, including energy mix and industrial specialization, may mediate the link between global economic integration and emissions.

GDP per capita demonstrates a robust and positive association with emissions, with coefficients of 6.308 under panel OLS and 6.102 under random effects. Greater per capita income often spurs higher consumption of energy-intensive goods and services, expanded infrastructure projects, and increased private vehicle use, collectively translating into greater emissions (Ng, 2021). At the same time, the significant and negative coefficient on the squared term of GDP per capita, which stands at -2.276 for panel OLS and -2.116 for random effects, reinforces the existence of a non-linear path where emissions initially climb with rising income but may decline at more advanced stages of economic development. This pattern aligns with the Environmental Kuznets Curve hypothesis, which posits that countries achieving higher income levels can eventually adopt cleaner production methods, stricter environmental policies, and service-oriented economic structures, thereby reducing emissions intensity (Ahmad & Ali, 2022).

The addition of the GDP growth rate and its squared term brings an extra layer of complexity to the discussion. In the panel OLS model, the GDP growth rate exhibits a small but significant negative coefficient (-0.010), while in the random effects model, the relationship is positive and significant (0.0039). These contradictory signs can be interpreted to mean that moderate economic expansions might coincide with modest emissions reductions, perhaps reflecting cyclical downturns in polluting sectors or incremental technological improvements. However, in other contexts, particularly when growth surges, emissions could rise in response to the scale effect of increased industrial production and consumption (Curtis, 2009). The consistently negative and significant squared term of GDP growth rate, which is -1.12 in the panel OLS model and -1.2407 in random effects, reveals that the relationship between growth and emissions is also non-linear. Initially, incremental improvements in productivity and energy efficiency might help restrain emissions, but after surpassing a certain threshold, further growth appears to overwhelm any earlier efficiency gains, leading to net increases in carbon output.

A notable aspect of these findings involves manufacturing value-added, which shows mixed outcomes. In the panel OLS model, the coefficient of 1.67 is not statistically significant, explaining an ambiguous relationship. In the random effects model, however, the coefficient of -1.109 is significant and indicates that growth in manufacturing value added can be associated with a decline in carbon emissions. One plausible explanation is that the manufacturing sector, in many countries, is undergoing technological upgrading and structural transformation, shifting away from heavy, high-emission industries to more specialized and efficient production methods (Song et al., 2023).

Table 5: Panel Results

CO2: Dependent variables

Variables	Panel OLS CO2			Random effect CO2		
	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3
EG	0.014***	0.027	.0113	0.0151*	0.01***	0.014**
EG^2		-5.055	-6.502		-8.61*	-6.322**
YPC	6.11***	5.98***	6.308***	6.11***	5.98***	6.102***
YPC^2	-2.18***	-2.16***	-2.276***	-2.18***	-2.16***	-2.116***
Yg			-0.010***			0.0039***
Yg^2			-1.12***			-1.2407***
MFG	-7.37***	-7.27***	1.67	-7.37***	-7.27***	-1.109***
PG	0.0065	0.003	-0.011***	0.0015	0.003	0.0022
SG	0.0032	0.004	0.053***	0.0034	0.004	0.005
Observations	5131	5131	5131	5132	5131	5131

***, ** represents the level of 1% and 5% level of significant.

Political globalization displays a small but significant negative coefficient (-0.011) in the panel OLS model, hinting that enhanced political collaboration can contribute to emission reductions. However, the coefficient of 0.0022 in the random effects model is not statistically significant, underscoring that these alliances may not always translate into uniform or immediate changes in a country's environmental trajectory. Enforcement of global protocols and agreements can be uneven, and countries differ in their capacity or willingness to align domestic policies with international standards (Abbott & Snidal, 2001). Over longer periods, cooperative political relationships can ease the diffusion of greener technologies and encourage policy harmonization, yet short-run or mid-term effects may remain limited if economic priorities take precedence over environmental goals.

Social globalization, encompassing transnational cultural, informational, and interpersonal connections, yields a positive coefficient of 0.053 in the panel OLS model, signifying a link between higher social connectivity and rising emissions. One possible mechanism is the global diffusion of consumption-driven lifestyles, where modern amenities, travel, and imported goods intensify energy use (Markusen & Schrock, 2009). However, the random effects estimate of 0.005 is statistically insignificant, suggesting that once unobserved heterogeneity is controlled, the influence of social integration on emissions may not hold across the broader panel. The differing results might be explained by cultural variance, institutional development, or the presence of local environmental advocacy movements, all of which could mediate how social globalization translates into actual emission outcomes. In some contexts, social globalization may foster awareness and environmental activism, while in others it could amplify consumerist trends that drive up energy demand.

6. CONCLUSIONS

This study set out to examine whether different dimensions of globalization—economic, political, and social—alongside standard economic drivers (GDP per capita, GDP growth, and manufacturing value added), exhibit a U-shaped or inverted U-shaped relationship with CO_2 emissions in a worldwide panel framework. Using multiple model specifications (Models 1, 2, and 3) and alternative estimation methods (panel OLS and random effects) provides a robust indication of an inverted U-shaped pattern between GDP per capita and CO_2 emissions across all models. Specifically, rising income initially accelerates emissions, but beyond a certain GDP per capita threshold, further increases in income coincide with reduced emission intensity. These findings confirm that, as economies evolve and industrial structures mature, cleaner technologies and stronger regulations can help mitigate pollution. Economic globalization generally correlates positively with CO_2 emissions, though its magnitude and significance differ based on the model and estimation technique. When significant, deeper engagement in global trade and financial networks seems to elevate emissions—consistent with scale effects and possibly linked to the "pollution haven" hypothesis, where carbon-intensive production may shift to regions with more relaxed regulations. Still, in some analyses, the effect is smaller or statistically insignificant, implying that national factors (e.g., technological capacity, energy mix, regulatory approaches) determine how globalization influences environmental outcomes. Political globalization (e.g., international treaties, diplomatic networks) and social globalization (e.g., cross-border cultural exchange, information flows) typically display marginal or insignificant direct impacts on emissions in most specifications. While global political collaborations can, in principle, raise environmental standards, concrete and uniform shifts do not always materialize, possibly owing to inconsistent enforcement or prolonged delays before policies become operational. Social globalization may diffuse both resource-intensive lifestyles and ecological awareness; the net impact on emissions appears too context-dependent for consistent, near-term statistical significance. In the majority of specifications, higher manufacturing value added has either a negative or insignificant association with CO_2 emissions. A negative coefficient suggests that, in some settings, the manufacturing sector is upgrading technologies, boosting energy efficiency, or gravitating toward higher value-added (and lower carbon-intensive) outputs, potentially "decoupling" industrial progress from carbon emissions. However, such benefits may hinge on technological advances, the presence of stricter rules, and an orientation toward cleaner production methods. Including the GDP growth rate (and its squared term) in Model 3 adds depth to the growth–emissions debate. Moderate growth may align with incremental efficiency gains, yet very rapid growth can outweigh technological progress, causing net increases in emissions. This underscores the importance of growth pace—not only its level—in shaping environmental pressures.

6.1. POLICY RECOMMENDATIONS

Since economic globalization often raises emissions in lower- and middle-income nations, policymakers should strengthen environmental standards to avert a "race to the bottom." Tighter monitoring and robust enforcement of pollution limits can deter industries from exploiting weaker regulatory conditions.

The mixed (and sometimes negative) impact of manufacturing value added on CO_2 implies that shifting to more efficient, high-value-added production can help decouple growth from emissions. Policies encouraging firms to adopt cleaner equipment, invest in automation, and incorporate renewable energy can reinforce these gains.

Though political globalization's direct effect on emissions is generally modest in the near term, international agreements and diplomatic channels are indispensable for technology exchange, capacity-building, and climate finance. Policymakers should proactively participate in multilateral initiatives (e.g., the Paris Agreement) to leverage research collaborations and green innovation funds.

Social globalization can spread both resource-heavy consumption habits and stronger environmental awareness. Governments, NGOs, and international agencies should leverage global media, cultural projects, and educational outreach to promote sustainable consumption, recycling, and green technologies—thus steering social globalization's influence toward decreasing emissions.

Given that GDP per capita and GDP growth rate both substantially affect emissions, decision-makers should pursue balanced, moderate growth trajectories aligned with sustainability. Fiscal mechanisms (e.g., carbon levies, clean-energy subsidies) and industrial policies (e.g., targeted R&D incentives, green bond issuance) enable economies to channel expansion into low-carbon pathways.

Globalization's varied environmental repercussions across different regions call for context-sensitive strategies. High-income nations might sustain their technological lead in renewables and circular-economy programs, whereas emerging economies may emphasize affordable clean technologies, better regulatory enforcement capacity, and green-oriented foreign investment.

Future Research could refine these insights by employing alternate globalization metrics (e.g., digital integration), incorporating energy-specific indicators (renewable vs. nonrenewable consumption), or investigating sector-based emissions. Country-focused or region-centered assessments would further clarify how local institutional capacity and technological readiness mediate the globalization–environment linkage. Overall, the study highlights that realizing globalization's developmental benefits without undermining the environment demands not only open markets but deliberate strategies encompassing environmental policies, technology diffusion, sociopolitical cooperation, and public engagement programs.

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