

Six Paths to Sustainability: Unveiling the Economic, Social, and Technological Forces Shaping Environmental Futures in Emerging Economies

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Abstract

This study investigates the complex interplay between socio-economic, environmental, and technological factors and their influence on carbon dioxide (CO₂) emissions across a diverse sample of 28 countries from 2006 to 2018. The research aims to uncover how global integration, financial integration, trade investment, technological and digital connectivity, infrastructure, and other macroeconomic variables such as GDP growth, energy intensity, and urbanization contribute to the carbon footprint. The relevance of this study lies in its potential to inform policy interventions that balance economic growth with environmental sustainability. Utilizing robust datasets from the Asia Regional Integration Centre and the World Bank, this study employs advanced econometric techniques, including Fixed Effects, Random Effects, and System Generalized Method of Moments (SYS-GMM) models. The findings reveal that energy intensity consistently drives CO₂ emissions across all models, underscoring the critical need for policies that enhance energy efficiency. Urban growth is also identified as a significant predictor of emissions, highlighting the environmental challenges associated with rapid urbanization. Conversely, technological and digital connectivity is found to reduce CO₂ emissions, suggesting that advancements in digital technologies can mitigate environmental impacts. The study also identifies context-dependent effects of global and financial integration on emissions, with implications for sustainable development policies. This research contributes to the existing literature by providing empirical evidence on the multifaceted relationships between socio-economic factors and CO₂ emissions. It emphasizes the need for a multidimensional approach to environmental policy, integrating economic, technological, and global factors to effectively address climate change. These insights can guide the formulation of targeted interventions to achieve sustainable development goals.

Keywords: Carbon emissions; Digital connectivity; Emerging economies; Energy intensity; Global integration; Urbanization

JEL Codes: O13; Q01; Q20; Q56; Q57

1. Introduction

Increased levels of carbon dioxide (CO₂) emissions showing serious repercussions on global climate, affecting atmospheric conditions and eco-system which is leading to rise in extreme events (Subramanian et al., 2023). It's a known fact that increased concentration of CO₂ directly influences summer temperatures, excessive precipitation and heat stress leading to natural calamities across the world (Ghazali et al., 2018). Therefore, its vital to set targets on future levels of CO₂ emissions to mitigate the risks associated with it. Even, if global commitments tend to reduce their emissions in the coming years, see for e.g., commitment from European Union to emit 55% less emissions by 2030 when compared to their 1990 levels (Lamberts-Van Assche et al., 2023); the long-lasting and irreversible changes in climate (Dwivedi et al., 2022) because of historical emissions will take time, as the transfer of elevated CO₂ emissions into the ocean resulting in increased atmospheric changes (Kabir et al., 2023). The projections for increased sea-levels ranges from 0.4 to 1.9 metres, depending on the peak level of CO₂ concentration and costal region and fragile ecosystems facing significant risks as a result of this situation (Bamber et al., 2019; Levy et al., 2024). Authors have considered carbon pricing as one of the effective way to deal with climatic change and to transform the world on sustainable path (Dales, 2002; Nordhaus, 2019; Pigou, 2017; Pindyck, 2019; Stern, 2007); although following the principle of welfare economics, the cost of mitigating climate change is crucial for formulating climate policy which focuses on the political feasibility of decarbonization (Bretschger, 2024). These policy changes are going to create business opportunities as well and also leading to commitment from corporates towards climate change (Hakovirta et al., 2023). Action points for mitigating climate change involves structural transformation, like, transition from fossil-fuels to renewable energy sources, innovating agricultural practices, technology advancements in energy-efficient buildings and manufacturing process, along with life-style changes from the population. These measures collectively going to influence the supply-demand, reshaping the consumption and production patterns across society (Clora and Yu, 2022). As these are collective efforts on a global scale, the integration of a country into the global economy plays a critical role, as shifting to cleaner sources of energy requires a multi-dimensional approach. Global integration influences environment in three ways: the income effect, the composition effect and the technique effect (Shahbaz et al., 2018). It is different from participation of a country in global value chain which has been widely researched in context of environmental studies (Meng et al., 2018).

This research gets on an empirical examination to distinguish the socio-economic and environmental factors influencing CO₂ emissions, using robust datasets from the Asia Regional Integration Centre and the World Bank. It methodically evaluates how variables such as global integration, financial integration, trade and investment, technological and digital connectivity, and social cohesion impact CO₂ emissions. Additionally, the study examines the effects of infrastructure quality, GDP growth, energy intensity, inflation rates, political stability, and urbanization rates on emissions. Through this empirical analysis, the research targets to deliver nuanced understandings that could direct the formulation of all-inclusive and applicable environmental policies, ultimately contributing to the global efforts towards sustainable development.

Understanding the complex dynamics of carbon emissions in relation to a varied array of socio-economic and environmental variables is not simply an academic exercise but a critical step towards effective climate action. The necessity to investigate these variables stem from their direct and indirect influence on the atmospheric concentrations of CO₂, which are essential in determining global climate models and thereby shaping both human and ecological systems. For instance, global integration influence emissions via various modes; it can spearhead enhanced environmental standards and expertise through the income and technique effects but may also build-up emissions due to strengthened industrial activity under the composition effect (Cetin et al., 2018; Wu et al., 2022). Similarly, financial integration has the potential to impact carbon dioxide (CO₂) emissions in both positive and negative ways, depending on the mechanisms involved. The impact's complexity is shaped by various factors, including economic growth, energy consumption, industrialization, and the advancement of sustainable technologies. The duality of financial integration is apparent in various regions and contexts. (Adams and Kaffo Fotio, 2024; Gao et al., 2024) highlighted positive effects of financial integration on emissions via financial inclusion and flow of funds, whereas, (Shen et al., 2024) stressed on the negative effect of it.

The correlation between trade investments and technological advancements poses various prospects and obstacles. It can support the dissemination of low-emission technologies and practices. Alternatively, if influenced by carbon-intensive industries, it could potentially lead to higher emissions. Effective social integration is essential for promoting community-driven and policy-supported initiatives that shape public behaviors and norms in support of sustainability. Infrastructure is a vital component of economic activities, as it has a direct impact on emissions due to its efficiency and commitment to sustainability.

Furthermore, examining economic growth indicators like GDP growth and energy intensity provides a macroeconomic viewpoint on emissions trajectories. They offer valuable insights into the relationship between economic development and environmental impact. The phenomenon of inflation has a significant influence on the prices that consumers encounter, subsequently altering their consumption habits and potentially leading to shifts in emissions. Political stability facilitates the consistent implementation of environmental policies, while urbanization rates provide insights into the challenges and opportunities of managing emissions in rapidly expanding urban areas.

The objective of this study is to analyse the relationship between various factors that impact CO₂ emissions. The goal is to gain insights into how economic and policy interventions can be optimized to efficiently decrease the carbon footprint. This analysis holds great importance for the academic community and can serve as a valuable resource for policymakers. It assists in achieving a harmonious equilibrium between economic progress and environmental preservation, empowering individuals to devise efficient and flexible strategies applicable in diverse global settings. It is essential to have a comprehensive understanding in order to formulate strategies that effectively tackle climate impacts while simultaneously promoting sustainable development and economic resilience.

2. Review of literature

The relationship between economic activity and carbon emissions is well-established, with Gross Domestic Product (GDP) growth often cited as a primary driver of increased emissions. As economies expand, energy consumption and industrial activities typically rise, leading to higher greenhouse gas emissions. This positive correlation has been confirmed by numerous studies across different regions and time periods. For instance, Alshehry and Belloumi (2015) demonstrated that GDP growth in Saudi Arabia significantly influences carbon emissions, both in the short and long term, consistent with the scale effect where increased economic activity results in higher energy use and emissions. Similarly, Azam et al. (2016) found that GDP growth was a crucial factor in driving CO₂ emissions across 107 countries, attributing this to the expansion of energy-intensive industries and infrastructure. Karaaslan and Çamkaya (2022) echoed these findings in Turkey, linking GDP growth to rising CO₂ emissions and highlighting the nation's reliance on non-renewable energy sources.

These studies collectively underscore the urgent need for policymakers to address the environmental consequences of economic growth. The complex interplay between economic growth and environmental degradation is further complicated by inflation, which can also influence carbon emissions. Rehman et al. (2020) revealed that in Pakistan, inflation positively impacts CO₂ emissions, suggesting that higher inflation rates may incentivize energy-intensive production methods while discouraging investments in clean technologies. However, Grolleau and Weber (2024) offered a contrasting perspective, finding a modest but significant negative relationship between core inflation and CO₂ emissions, indicating that inflation could have a mitigating effect on emissions, albeit insufficient to achieve substantial reductions. The nuanced relationship between inflation and emissions is further explored by Rahman et al. (2024), who noted that inflation specifically exacerbates carbon emissions in the agricultural sector in Pakistan, necessitating targeted interventions to counteract this trend.

These divergent findings highlight the complex dynamics between inflation and carbon emissions, suggesting that inflation's impact on environmental outcomes may vary significantly depending on the economic context and sectoral focus. Urbanization, a key driver of economic transformation, also plays a significant role in shaping carbon emissions. The migration of populations from rural to urban areas typically leads to increased energy consumption and emissions from transportation, buildings, and industry. This relationship has been documented extensively, though the findings are far from uniform. Zhu and Hui-Ming (2012) uncovered a nonlinear relationship between urbanization and CO₂ emissions in emerging countries, revealing that the expected reduction in emissions at higher urbanization levels is not consistently observed. Liddle and Lung (2010) similarly found that urbanization in OECD nations significantly drives CO₂ emissions, advocating for urban planning and infrastructure development that supports energy-efficient technologies. However, Sadorsky (2014) and Abdallah and Abugamos (2017) provided contrasting evidence, suggesting that in emerging economies, the impact of urbanization on emissions is statistically insignificant or even negative.

These studies suggest that while urbanization is generally associated with higher emissions, its effects are highly context-dependent, varying across regions and levels of development. Consequently, policy responses to urbanization's environmental impact must be tailored to local conditions, considering both the potential benefits and challenges of urban growth. Global integration, encompassing trade openness and financial liberalization, presents another critical dimension in the carbon emissions discourse. Theoretically, the impact of global integration on

emissions is ambiguous, with potential for both positive and negative outcomes. On the one hand, greater openness to trade and investment can facilitate the diffusion of green technologies and cleaner production methods, as suggested by Frankel and Rose (2005), who found that freer trade tends to reduce emissions by encouraging the adoption of environmentally friendly technologies.

Copeland and Taylor (2004) similarly noted that increased trade can spur the diffusion of technology and the reallocation of production towards less pollution-intensive sectors. However, other studies offer a more cautionary tale. Shahbaz et al. (2013) reported that in Indonesia, both trade openness and foreign direct investment (FDI) inflows significantly increased CO₂ emissions, driven by the scale effect of increased economic activity. Hasanov (2018) also highlighted the role of financial openness in exacerbating carbon emissions, particularly in oil-exporting countries. These findings suggest that while global integration can promote environmental sustainability under certain conditions, it may also exacerbate emissions if scale effects outweigh the benefits of technological diffusion. The literature on financial liberalization and its environmental impact further complicates the picture. While financial integration has the potential to facilitate investments in clean energy technologies and green infrastructure, it can also lead to increased emissions if it stimulates energy-intensive industrialization.

Tamazian et al. (2009) argued that financial liberalization in BRIC countries has been associated with lower CO₂ emissions, as financial development encourages the reallocation of production towards cleaner industries. Conversely, Shahbaz et al. (2013) found that financial development in Indonesia led to higher emissions, highlighting the potential for financial integration to exacerbate environmental degradation under certain conditions. Qin et al. (2021) provided a more nuanced view, suggesting that financial inclusion can reduce emissions at lower quantiles, while globalization and renewable electricity consistently curb emissions. These studies underscore the importance of context in understanding the environmental implications of financial integration, suggesting that the stage of financial development and the broader economic environment are critical factors in determining outcomes.

Beyond global and financial integration, other dimensions of economic globalization, such as trade and investment, have been linked to carbon emissions. The mechanisms here are similar to those for global integration, with potential for both positive and negative effects. Jalil and Feridun (2011) found that in China, both exports and FDI inflows positively impacted CO₂

emissions, driven by the scale effect. Nondo et al. (2016) reached similar conclusions in their cross-country analysis of 19 African nations, where trade openness and FDI were associated with greater carbon outputs. However, Kiviyiro and Arminen (2014) offered a more optimistic view, finding that in some sub-Saharan African countries, FDI inflows had a negative effect on emissions, potentially due to the transfer of cleaner production technologies.

These mixed findings suggest that the environmental impact of trade and investment is highly context-dependent, with the potential for both positive and negative outcomes depending on the specific circumstances. Digital connectivity, a more recent aspect of economic globalization, also plays a role in shaping carbon emissions. On one hand, digital technologies can reduce energy use and emissions by enabling telecommuting, online shopping, and the dematerialization of economic activities. On the other hand, the production and use of digital technologies require energy and can contribute to emissions. Zafar et al. (2019) found that in 25 advanced economies, increased ICT adoption had a negative and statistically significant effect on carbon outputs, suggesting that the environmental benefits of digital technologies outweighed the costs.

Benavides et al. (2017) similarly found that greater ICT infrastructure and usage were associated with reduced CO₂ emissions in Latin American and Caribbean countries. However, Mohammad Salahuddin (2016) found a significant positive relationship between Internet usage and CO₂ emissions in OECD countries, indicating that the environmental impact of digital connectivity may vary across regions and levels of development. These findings suggest that while digital technologies have the potential to reduce emissions, their environmental impact is complex and context dependent. Infrastructure development is another critical factor influencing carbon emissions. The construction, operation, and maintenance of infrastructure can generate significant greenhouse gas emissions, but well-designed and sustainable infrastructure can also contribute to emissions reductions. Riti et al. (2017) found that infrastructure development in China contributes to increased CO₂ emissions, driven by energy consumption.

However, they also noted that in the long run, increased per capita GDP could reduce emissions, supporting the Environmental Kuznets Curve (EKC) hypothesis. Bakhsh et al. (2017) offered a contrasting perspective in Pakistan, where greater infrastructure development was associated with reduced CO₂ emissions, likely due to the adoption of energy-efficient technologies. These studies highlight the dual role of infrastructure in both contributing to and mitigating emissions,

emphasizing the need for targeted investments in sustainable infrastructure to achieve environmental goals. Finally, green investment emerges as a crucial strategy for reducing carbon emissions. Huang et al. (2021) emphasized the importance of green investment in abating CO₂ emissions in China, finding a significant negative impact on emissions.

This finding aligns with the broader literature on the role of green investment in mitigating carbon emissions, suggesting that targeted financial flows towards environmentally friendly projects and technologies can have a significant impact on reducing CO₂ outputs. The bidirectional relationship identified by Huang et al. (2021) also highlights the complex interplay between economic policies and environmental outcomes, emphasizing the need for integrated approaches to sustainable development. In conclusion, the literature on the relationship between economic activity, globalization, and carbon emissions reveals a complex and multifaceted set of dynamics. While economic growth, urbanization, and global integration often drive higher emissions, targeted policies and investments, particularly in green technologies and sustainable infrastructure, have the potential to mitigate these effects.

Policymakers must navigate these complexities to balance economic development with environmental sustainability, recognizing that the impact of these factors is highly context-dependent and varies across regions and levels of development. The existing literature provides valuable insights into the relationship between economic activity and carbon emissions, but several important gaps remain. One notable gap lies in the regional and contextual variability of these relationships. While many studies confirm a positive correlation between GDP growth and CO₂ emissions, the specific factors driving this relationship can differ significantly across regions and levels of development. For instance, the impact of urbanization on emissions is highly context-dependent, with some studies identifying a positive correlation while others find it to be statistically insignificant or even negative. This suggests that future research could benefit from cross-regional comparative analyses that delve into why these differences exist and how local factors—such as energy mix, regulatory frameworks, and economic structure—influence the economic activity-emissions relationship. Another gap concerns the complex and not well-understood relationship between inflation and CO₂ emissions.

While some studies suggest that inflation increases emissions by promoting energy-intensive production methods, others find a modest negative relationship. The mechanisms through which inflation affects emissions are not fully explored, leaving room for more detailed research to disentangle the specific channels, particularly in sector-specific contexts and the

role of monetary policy in environmental outcomes. Similarly, the literature on urbanization presents inconsistent findings, particularly regarding the nonlinear relationship between urbanization and carbon emissions. Given these discrepancies, further research could explore the underlying factors, such as urban planning, infrastructure quality, and energy efficiency measures, that drive these divergent outcomes.

Finally, the relationship between global integration, including trade openness and financial liberalization, and carbon emissions remains ambiguous. Some studies highlight the diffusion of green technologies through global integration, while others argue that it exacerbates emissions through scale effects. This ambiguity points to the need for more nuanced studies that account for the varying impacts of global integration across different economic contexts and development stages. Addressing these gaps would provide a more comprehensive understanding of how economic growth, inflation, urbanization, and global integration interact with environmental sustainability.

3. Data and methodology

3.1. Data

This empirical research utilizes annual data spanning from 2006 to 2018 for a sample of 28 countries, including Algeria, Bangladesh, Brazil, Bulgaria, Chile, China, Colombia, Costa Rica, Ecuador, India, Indonesia, Kazakhstan, Latvia, Lithuania, Malaysia, Mexico, Morocco, Pakistan, Peru, the Philippines, Poland, Portugal, Slovakia, Slovenia, South Africa, Sri Lanka, and Thailand. The selection of these countries provides a diverse representation of emerging and developing economies, which is essential for understanding the socio-economic and environmental factors influencing carbon dioxide (CO₂) emissions across different regions. The dependent variable in this study is Carbon Dioxide Emissions (Annual_CO₂), sourced from Our World in Data. This variable measures the total annual CO₂ emissions in each country, serving as a key indicator of environmental impact.

The study aims to explore how various economic, social, and infrastructural factors influence CO₂ emissions across the selected countries over the specified period. A comprehensive set of independent variables has been included to capture the multifaceted influences on CO₂ emissions. The Global Integration Index (Global Integration), sourced from the Asia Regional Integration Center, reflects the degree of a country's integration into the global economy, encompassing factors such as trade openness, foreign direct investment (FDI), and participation in global value chains. Financial Integration (Money and Finance), also derived from the Asia Regional Integration Center, captures the level of financial connectivity with global markets, reflecting the extent to which a country is integrated into the international financial system. Additionally, the Trade and Investment (Trade Investment) variable, sourced from the same center, measures the scale and intensity of trade and investment activities, which are crucial determinants of economic growth and development.

The study also incorporates the Technology and Digital Connectivity (Tech Digital Connectivity) variable, representing the level of technological advancement and digital infrastructure, which can influence energy consumption patterns and, consequently, CO2 emissions. This data is also sourced from the Asia Regional Integration Center. Furthermore, Social Integration (People and Social Integration) assesses the degree of social cohesion and integration within a country, which can impact policy implementation and public support for environmental initiatives. The Infrastructure and Connectivity (Infrastructure Index) variable measures the quality and extent of physical infrastructure, such as transportation networks and energy systems, and is critical for understanding the role of infrastructure development in influencing CO2 emissions.

Economic indicators from the World Bank are also included in the analysis. GDP Growth (annual %) (GDP Growth) is used to measure the economic performance of each country, providing insights into the relationship between economic expansion and environmental impact. The Energy Intensity Level of Primary Energy (Energy Intensity) reflects the efficiency of energy use within an economy, which is a key factor in determining CO2 emissions. Inflation (Inflation) is considered to account for macroeconomic stability, which can influence investment in sustainable technologies and energy efficiency measures. Political Stability (Political Stability) is included to examine the role of governance and institutional quality in shaping environmental outcomes. Lastly, Urban Population Growth (annual %) (Urban Growth Rate) captures the rate of urbanization, which is often associated with increased energy demand and higher CO2 emissions due to the concentration of economic activities in urban areas.

Table 1. Variable

Variable	Label	Source
Carbon Dioxide Emissions	Annual_CO2	Our world in data
Global Integration Index	Global Integration	Asia Regional Integration Center
Money and Finance	Financial Integration	Asia Regional Integration Center
Trade and Investment	Trade Investment	Asia Regional Integration Center
Technology and Digital Connectivity	Tech Digital Connectivity	Asia Regional Integration Center
People and Social Integration	Social Integration	Asia Regional Integration Center
Infrastructure and Connectivity	Infrastructure Index	Asia Regional Integration Center
GDP growth annual %	GDP Growth	World Bank
Energy intensity level of primary energy	Energy Intensity	World Bank
Inflation	Inflation	World Bank
Political Stability	Political Stability	World Bank
Urban population growth (annual %)	Urban Growth Rate	World Bank

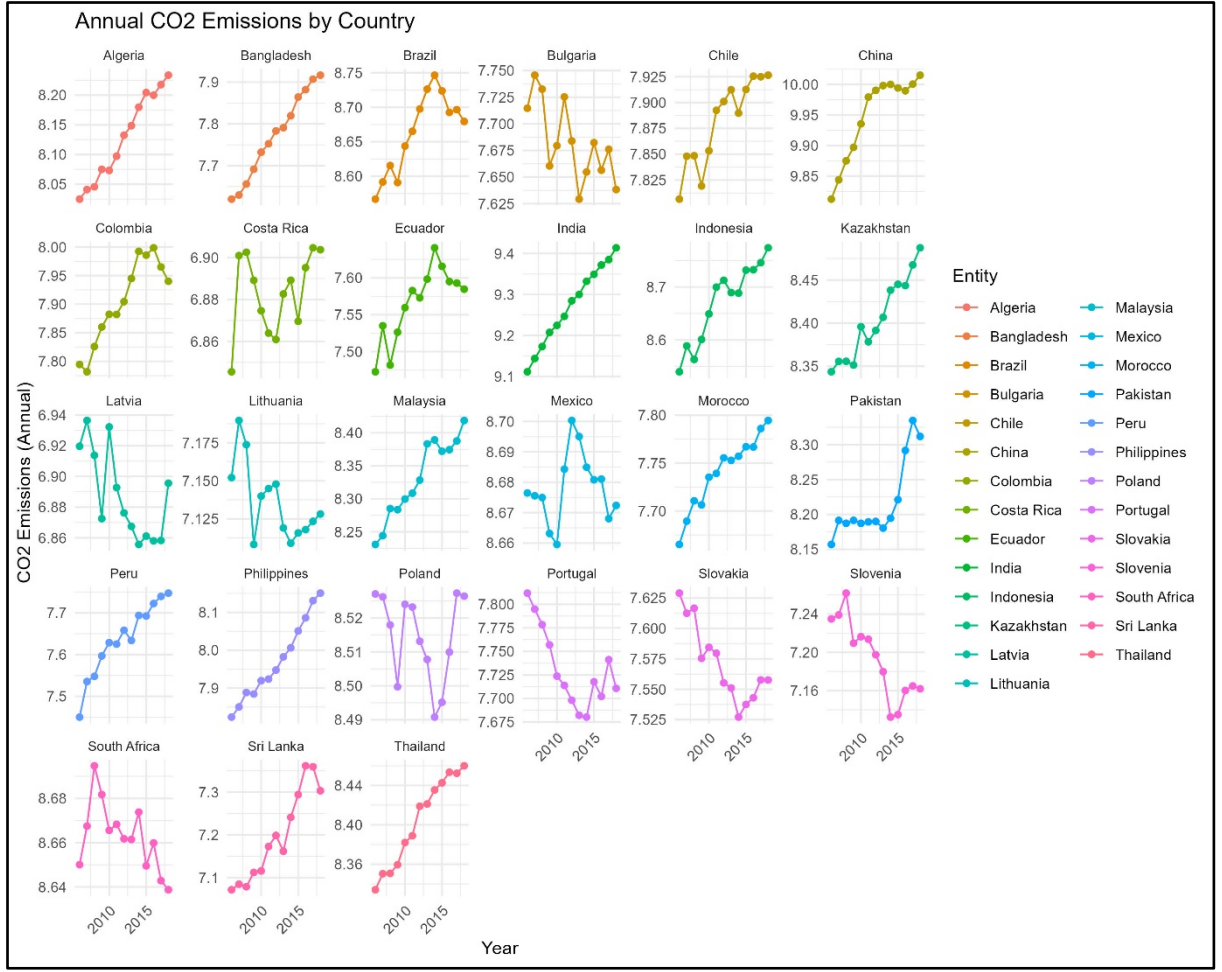


Figure 1. Annual CO2 emission for all sample countries

3.2. Methodology

For this study, we have developed six models, and we have adopted the Fixed effect, Random effect and SYS-GMM methodology

Model 1

$$ANNUAL\ Co2_{i,t} = \alpha_{i,t} + \beta_1 Energy\ Intensity_{i,t} + \beta_2 Inflation_{i,t} + \beta_3 Urban\ Growth\ Rate_{i,t} + \beta_4 GDP_Growth_{i,t} + \beta_5 Global\ Integration_{i,t} \quad (1)$$

Model 2

$$ANNUAL\ Co2_{i,t} = \alpha_{i,t} + \beta_1 Energy\ Intensity_{i,t} + \beta_2 Inflation_{i,t} + \beta_3 Urban\ Growth\ Rate_{i,t} + \beta_4 GDP_Growth_{i,t} + \beta_5 Financial_Integration_{i,t} \quad (2)$$

Model 3

$$ANNUAL\ Co2_{i,t} = \alpha_{i,t} + \beta_1 Energy\ Intensity_{i,t} + \beta_2 Inflation_{i,t} + \beta_3 Urban\ Growth\ Rate_{i,t} + \beta_4 GDP_Growth_{i,t} + \beta_5 Infrastructure_Index_{i,t} \quad (3)$$

Model 4

$$ANNUAL\ Co2_{i,t} = \alpha_{i,t} + \beta_1 Energy\ Intensity_{i,t} + \beta_2 Inflation_{i,t} + \beta_3 Urban\ Growth\ Rate_{i,t} + \beta_4 GDP_Growth_{i,t} + \beta_5 Political_Stability_{i,t} \quad (4)$$

Model 5

$$ANNUAL\ Co2_{i,t} = \alpha_{i,t} + \beta_1 Energy\ Intensity_{i,t} + \beta_2 Inflation_{i,t} + \beta_3 Urban\ Growth\ Rate_{i,t} + \beta_4 GDP_Growth_{i,t} + \beta_5 Trade_Investment_{i,t} \quad (5)$$

Model 6

$$ANNUAL\ Co2_{i,t} = \alpha_{i,t} + \beta_1 Energy\ Intensity_{i,t} + \beta_2 Inflation_{i,t} + \beta_3 Urban\ Growth\ Rate_{i,t} + \beta_4 GDP_Growth_{i,t} + \beta_5 Tech_Digital_Connectivity_{i,t} \quad (6)$$

4. Results and discussion

This study incorporates a series of preliminary diagnostic tests to ensure the robustness and reliability of the data utilized in the analysis, in order to elucidate the multifaceted determinants of carbon dioxide emissions. The following tables provides an overview of the descriptive statistics, panel unit root tests, cross-sectional dependence tests, and homogeneity tests conducted for the different models used in this study.

Table 2. Descriptive

	Mean	Max	Min	Std. Dev.	Jarque-Bera	N
ANUUAL_CO2	8.024	10.015	6.846	0.705	20.162	351
ENERGY_INTENSITY	0.596	1.017	0.217	0.160	4.188	351
FINANCIAL_INTEGRATION	-0.256	-0.038	-0.671	0.100	103.752	351
GDP_GROWTH	0.564	1.171	-1.005	0.316	187.892	351
GLOBAL_INTEGRATION	-0.333	-0.198	-0.523	0.075	11.893	351
INFLATION	0.480	1.353	-1.757	0.449	412.054	351
INFRASTRUCTURE_INDEX	-0.309	-0.092	-0.609	0.091	3.193	351
POLITICAL_STABILITY	1.462	1.961	-0.324	0.416	231.825	351
SOCIAL_INTEGRATION	-0.642	-0.211	-1.302	0.233	38.616	351
TECH_DIGITAL_CONNECTIVITY	-0.488	-0.089	-1.326	0.241	46.270	351
TRADE_INVESTMENT	-0.578	-0.118	-1.080	0.219	13.589	351
URBAN_GROWTH_RATE	0.127	0.610	-1.598	0.387	216.966	351

Table 3. Panel unit root and cross-sectional dependence tests for variables in energy security and equity models

Variable	CD-test	CIPS	CADF
Annual_CO2	45.69***	-4.083***	-4.252***
Global Integration	61.454***	-5.61***	-4.056***
Financial Integration	56.26***	-6.121***	-4.706***
Infrastructure Index	60.692***	-5.772***	-3.859***
Political Stability	59.664***	-6.145***	-5.165***
Energy Intensity	60.335***	-5.231***	-4.196***
GDP Growth	18.67***	-6.02***	-4.85***
Energy Equity	61.71***	-6.018***	-5.084***
Social Integration	60.948***	-5.998***	-4.791***

Urban Growth Rate	43.809***	-6.022***	-4.829***
Trade Investment	56.163***	-5.769***	-4.743***
Tech Digital Connectivity	58.59***	-6.138***	-4.396***
Inflation	28.623***	-6.006***	-4.902***

The table presents results from statistical tests—Cross-sectional Dependence (CD), Pesaran's Cross-sectional ImPes (CIPS), and Cross-sectional Augmented Dickey-Fuller (CADF)—used to analyze various economic and energy-related variables. The significance of the results is denoted by asterisks (***), indicating a significance level at 1%

Table 2 presents the descriptive statistics for the key variables utilized in the analysis of the factors influencing carbon dioxide emissions. The data encompasses a total of 351 observations. The variables examined encompass a range of factors, such as annual CO2 emissions, energy intensity, financial integration, GDP growth, global integration, inflation, infrastructure index, political stability, social integration, tech digital connectivity, trade investment, and urban growth rate. The average annual CO2 emissions are 8.024, with a relatively small range from 6.846 to 10.015. This suggests moderate variability, as shown by a standard deviation of 0.705. The Jarque-Bera statistic for this variable is 20.162, indicating a deviation from normality. The Energy Intensity, in contrast, has an average of 0.596 and shows very little variation around this average (with a standard deviation of 0.160), indicating a more focused distribution.

The data on Financial Integration reveals a negative mean value of -0.256, ranging from -0.671 to -0.038. This suggests that the majority of data points lean towards lower levels of integration. Additional evidence of this skewness is supported by the elevated Jarque-Bera statistic of 103.752. The dataset shows a range of economic variability in GDP Growth, with a mean of 0.564. The range spans from -1.005 to 1.171. Additionally, the significant Jarque-Bera statistic of 187.892 further indicates this variability. The data on inflation shows a wide range from -1.757 to 1.353, with an average of 0.480. It exhibits significant volatility, with a standard deviation of 0.449. Additionally, it has the highest Jarque-Bera value of 412.054 among all variables, indicating extreme non-normality. These findings suggest that there may be difficulties in creating accurate models, and it is important to carefully account for non-linear effects or transformations to ensure the reliability of the analysis.

The Urban Growth Rate exhibits a mean of 0.127, with a range of values from -1.598 to 0.610. These findings highlight notable urban dynamics and demographic shifts, as evidenced by a substantial Jarque-Bera statistic of 216.966. Understanding the impacts of urbanization on emissions requires a thorough consideration of this variability.

Table 4. Homogeneity Tests for CO2 Emissions Models

Model	Test Source	Delta	Adjusted Delta	p-value	Adjusted p-value
Model 1	Pesaran & Yamagata (2008)	-1.433	-1.665	0.152	0.096
	Blomquist & Westerlund (2013)	2.478	2.879	0.013	0.004
Model 2	Pesaran & Yamagata (2008)	-1.126	-1.308	0.260	0.191
	Blomquist & Westerlund (2013)	7.471	8.681	0.000	0.000
Model 3	Pesaran & Yamagata (2008)	-1.373	-1.596	0.170	0.111
	Blomquist & Westerlund (2013)	0.950	1.104	0.342	0.270
Model 4	Pesaran & Yamagata (2008)	-1.071	-1.244	0.284	0.213
	Blomquist & Westerlund (2013)	1.370	1.592	0.171	0.111
Model 5	Pesaran & Yamagata (2008)	-0.969	-1.126	0.332	0.260
	Blomquist & Westerlund (2013)	0.789	0.917	0.430	0.359
Model 6	Pesaran & Yamagata (2008)	-1.302	-1.513	0.193	0.130
	Blomquist & Westerlund (2013)	0.879	1.021	0.379	0.307

The provided table displays results from two statistical tests for heterogeneity across six models, utilizing methodologies from Pesaran & Yamagata (2008) and Blomquist & Westerlund (2013). These tests are designed to detect heterogeneity in slope coefficients across different units in a panel data setting.

The table 4 presents the results for Model 1 from three different models: Fixed Effects, Random Effects, and System Generalized Method of Moments (SYS-GMM). The SYS-GMM model includes two lagged variables of annual CO2 emissions. The first lagged variable has a positive and statistically significant coefficient of 0.153 ($p < 0.01$). This suggests that a 1% increase in CO2 emissions in the previous period is associated with a 0.153% increase in current CO2 emissions. The second lagged variable, has a negative and statistically significant coefficient of -0.413 ($p < 0.01$), indicating that past emissions have a diminishing effect on current emissions over time. Energy Intensity is significant across all three models. In the Fixed Effects model, the coefficient is 2.686 ($p < 0.01$), indicating that a 1% increase in energy intensity leads to a 2.686% increase in CO2 emissions.

Table 4. Model 1

	(1)	(2)	(3)
VARIABLES	Fixed effects	Random effects	SYS-GMM
CO2 _{L1}			0.153*** (0.00685)
CO2 _{L2}			-0.413*** (0.0154)

Energy_Intensity	2.686*** (0.188)	2.507*** (0.190)	2.892*** (0.0728)
Inflation	0.244*** (0.0804)	0.117 (0.0757)	0.00835 (0.0359)
Urban_Growth_Rate	0.494*** (0.0827)	0.515*** (0.0852)	0.567*** (0.0252)
GDP_Growth	0.189* (0.0960)	0.0748 (0.0933)	-0.0164 (0.113)
Global_Integration	0.111 (0.490)	0.222 (0.495)	-1.033*** (0.197)
Constant	6.174*** (0.217)	6.440*** (0.217)	8.003*** (0.147)
Observations	351	351	325
R-squared	0.481		
Number of Year	13	13	13
Country FE	Yes		
Hausman Test		Yes	
Prob		YES	
AR 2			Yes
Hansen test			Yes

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

The Random Effects model provides a similar estimate of 2.507 ($p<0.01$), while the SYS-GMM model yields a slightly higher estimate of 2.892 ($p<0.01$). This consistent positive relationship across models suggests that higher energy intensity significantly contributes to CO2 emissions. Inflation is only significant in the Fixed Effects model, with a coefficient of 0.244 ($p<0.01$). This indicates that a 1% increase in inflation is associated with a 0.244% increase in CO2 emissions. The coefficient is positive but insignificant in the Random Effects model (0.117), and nearly negligible and insignificant in the SYS-GMM model (0.00835). The significant positive relationship in the Fixed Effects model suggests that inflation might contribute to emissions, but this effect is not robust across different model specifications. Urban Growth Rate is positively associated with CO2 emissions in all three models, with coefficients of 0.494 ($p<0.01$) in the Fixed Effects model, 0.515 ($p<0.01$) in the Random Effects model, and 0.567 ($p<0.01$) in the SYS-GMM model.

These results indicate that urban population growth is a strong and consistent driver of CO2 emissions, with each 1% increase in the urban growth rate leading to approximately a 0.5% to 0.57% increase in emissions. GDP Growth is significant only in the Fixed Effects model, with a coefficient of 0.189 ($p<0.1$), suggesting that economic growth may have a marginal positive impact on CO2 emissions. However, the Random Effects model (0.0748) and the SYS-GMM

model (-0.0164) show insignificant coefficients, indicating that the relationship between GDP growth and emissions is not consistent across different modelling approaches. Global Integration shows varied effects across the models. In the Fixed Effects model, the coefficient is 0.111, which is not statistically significant. Similarly, in the Random Effects model, the coefficient is 0.222, which also lacks significance. However, in the SYS-GMM model, the coefficient is negative and statistically significant at -1.033 ($p < 0.01$), suggesting that higher global integration might reduce CO2 emissions when controlling for endogeneity and dynamics in the data. This negative relationship indicates that global integration may facilitate more sustainable practices or technologies, leading to lower emissions.

Table 5. Model 2

VARIABLES	(1) Fixed effects	(2) Random effects	(3) SYS-GMM
CO2 _{L1}			0.151*** (0.0220)
CO2 _{L2}			-0.415*** (0.0147)
Energy_Intensity	2.699*** (0.177)	2.540*** (0.180)	2.756*** (0.0552)
Inflation	0.249*** (0.0799)	0.0847 (0.0729)	0.0138 (0.0301)
Urban_Growth_Rate	0.495*** (0.0794)	0.487*** (0.0816)	0.579*** (0.0374)
GDP_Growth	0.193** (0.0967)	0.0710 (0.0933)	-0.0328 (0.0634)
Financial_Integration	0.131 (0.341)	-0.227 (0.329)	-0.851*** (0.141)
Constant	6.158*** (0.140)	6.310*** (0.141)	8.242*** (0.185)
Observations	351	351	325
R-squared	0.481		
Number of Year	13	13	13
Country FE	Yes		
Hausman Test		Yes	
Prob		YES	
AR 2			Yes
Hansen test			Yes

Standard errors in parentheses
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table 5 presents the results for Model 2, specifically utilizing the SYS-GMM model, which incorporates two lagged variables of annual CO₂ emissions. The first lagged variable displays a positive and statistically significant coefficient of 0.151 ($p < 0.01$), indicating that a 1% increase in CO₂ emissions in the previous period is associated with a 0.151% increase in current emissions. In contrast, the second lagged variable exhibits a negative and statistically significant coefficient of -0.415 ($p < 0.01$), suggesting that the influence of past emissions diminishes over time, consistent with the findings from Model 1. Energy Intensity remains a significant predictor across all three models. The Fixed Effects model estimates a coefficient of 2.699 ($p < 0.01$), indicating that a 1% increase in energy intensity corresponds to a 2.699% increase in CO₂ emissions.

Similarly, the Random Effects model produces an estimate of 2.540 ($p < 0.01$), while the SYS-GMM model yields a slightly higher estimate of 2.756 ($p < 0.01$). The consistent positive relationship observed across these models underscores the strong and significant contribution of energy intensity to CO₂ emissions. Inflation's impact on CO₂ emissions varies depending on the model specification. In the Fixed Effects model, inflation is significant, with a coefficient of 0.249 ($p < 0.01$), suggesting that a 1% increase in inflation results in a 0.249% increase in CO₂ emissions. However, in the Random Effects model, the coefficient is positive but not statistically significant (0.0847), and in the SYS-GMM model, the coefficient is small and insignificant (0.0138). These mixed results imply that the effect of inflation on CO₂ emissions may depend on the specific model used, with the Fixed Effects model showing the strongest relationship. The Urban Growth Rate consistently exhibits a positive association with CO₂ emissions across all three models.

The coefficients are 0.495 ($p < 0.01$) in the Fixed Effects model, 0.487 ($p < 0.01$) in the Random Effects model, and 0.579 ($p < 0.01$) in the SYS-GMM model. These consistent findings indicate that urban population growth is a significant driver of CO₂ emissions, with each 1% increase in the urban growth rate leading to an approximately 0.5% to 0.58% increase in emissions. GDP Growth also shows a positive and significant coefficient of 0.193 ($p < 0.05$) in the Fixed Effects model, indicating that a 1% increase in GDP growth is associated with a 0.193% increase in CO₂ emissions.

However, this effect is not robust across different models, as the Random Effects model reports a positive but insignificant coefficient (0.0710), while the SYS-GMM model shows a negative and insignificant coefficient (-0.0328). The significant positive effect observed in the Fixed

Effects model suggests that economic growth may contribute to higher emissions, although this relationship is not consistently supported across all models. Financial Integration exhibits varied effects across the models. In the Fixed Effects model, the coefficient is positive (0.131) but not statistically significant, suggesting a weak positive relationship between financial integration and CO2 emissions. The Random Effects model shows a negative and insignificant coefficient (-0.227), providing no strong evidence of an effect. However, the SYS-GMM model reveals a negative and statistically significant coefficient of -0.851 ($p < 0.01$), indicating that higher financial integration may reduce CO2 emissions when accounting for endogeneity and dynamic effects. This finding implies that financial integration could potentially facilitate more sustainable investment and financial practices, leading to lower emissions.

Table 6. Model 3

VARIABLES	(1) Fixed effects	(2) Random effects	(3) SYS-GMM
CO2 _{L1}			0.181*** (0.0130)
CO2 _{L2}			-0.381*** (0.0195)
Energy_Intensity	2.607*** (0.177)	2.442*** (0.179)	2.818*** (0.0682)
Inflation	0.329*** (0.0770)	0.210*** (0.0730)	0.0860* (0.0413)
Urban_Growth_Rate	0.481*** (0.0760)	0.496*** (0.0776)	0.614*** (0.0411)
GDP_Growth	0.202** (0.0947)	0.0961 (0.0917)	-0.0138 (0.124)
Infrastructure_Index	1.083*** (0.344)	1.270*** (0.347)	0.144 (0.110)
Constant	6.472*** (0.163)	6.744*** (0.159)	7.899*** (0.165)
Observations	351	351	325
R-squared	0.496		
Number of Year	13	13	13
Country FE	Yes		
Hausman Test		Yes	
Prob		YES	
AR 2			Yes
Hansen test			Yes

Standard errors in parentheses
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table 6 presents the findings for Model 3. The SYS-GMM model incorporates two lagged variables of annual CO₂ emissions. The first lagged variable shows a positive and statistically significant coefficient of 0.181 ($p < 0.01$), showing that a 1% increase in CO₂ emissions from the previous period is linked to a 0.181% rise in current emissions. The second lagged variable presents a negative and statistically significant coefficient of -0.381 ($p < 0.01$), suggesting that the influence of past emissions on current levels decreases over time. The magnitude of these coefficients differs slightly from those in Models 1 and 2, reflecting some variability in the impact of past emissions when the Infrastructure Index is included. Energy Intensity continues to be a significant determinant of CO₂ emissions across all three models.

The Fixed Effects model estimates a coefficient of 2.607 ($p < 0.01$), implying that a 1% increase in energy intensity corresponds to a 2.607% increase in CO₂ emissions. The Random Effects model offers a similar estimate of 2.442 ($p < 0.01$), while the SYS-GMM model provides a slightly higher coefficient of 2.818 ($p < 0.01$). This persistent positive relationship across models underscores the strong influence of energy intensity on CO₂ emissions. Inflation consistently shows a positive and significant impact on CO₂ emissions across all models. The Fixed Effects model reports a coefficient of 0.329 ($p < 0.01$), suggesting that a 1% rise in inflation results in a 0.329% increase in CO₂ emissions. The Random Effects model also reflects a significant positive effect, with a coefficient of 0.210 ($p < 0.01$). In the SYS-GMM model, the effect is smaller but still positive and significant, with a coefficient of 0.0860 ($p < 0.1$).

These findings indicate that inflation has a consistent and robust positive effect on CO₂ emissions, although the extent of the effect varies across different models. The Urban Growth Rate remains positively correlated with CO₂ emissions across all three models, with coefficients of 0.481 ($p < 0.01$) in the Fixed Effects model, 0.496 ($p < 0.01$) in the Random Effects model, and 0.614 ($p < 0.01$) in the SYS-GMM model. These results suggest that urban population growth is a significant contributor to CO₂ emissions, with each 1% increase in the urban growth rate leading to an approximately 0.5% to 0.61% rise in emissions. The slightly higher coefficient in the SYS-GMM model may indicate a stronger effect when considering endogeneity and dynamic factors. GDP Growth shows a positive and significant coefficient of 0.202 ($p < 0.05$) in the Fixed Effects model, implying that a 1% increase in GDP growth is associated with a 0.202% increase in CO₂ emissions. However, the Random Effects model reports a positive but insignificant coefficient (0.0961), and the SYS-GMM model shows a small negative and insignificant coefficient (-0.0138).

These mixed outcomes suggest that while economic growth may contribute to emissions in certain contexts, its effect is not consistent across different model specifications. The Infrastructure Index is introduced in Model 3 as an additional predictor. The Fixed Effects model produces a coefficient of 1.083 ($p < 0.01$), indicating that infrastructure improvements are associated with higher CO2 emissions. The Random Effects model similarly shows a positive and significant effect, with a coefficient of 1.270 ($p < 0.01$). However, in the SYS-GMM model, the coefficient is considerably smaller and not significant (0.144), suggesting that the relationship between infrastructure development and emissions may weaken when accounting for endogeneity and dynamic factors. These results imply that while infrastructure development is generally linked to increased emissions, this relationship may not hold under more dynamic modeling conditions.

Table 7. Model 4

VARIABLES	(1) Fixed effects	(2) Random effects	(3) SYS-GMM
CO2 _{L1}			0.158*** (0.00952)
CO2 _{L2}			-0.375*** (0.0264)
Energy_Intensity	2.828*** (0.173)	2.668*** (0.176)	2.897*** (0.0814)
Inflation	0.137* (0.0726)	0.0111 (0.0684)	0.000463 (0.0555)
Urban_Growth_Rate	0.331*** (0.0810)	0.336*** (0.0835)	0.495*** (0.0157)
GDP_Growth	0.167* (0.0928)	0.0610 (0.0902)	-0.0357 (0.131)
Political_Stability	-0.380*** (0.0774)	-0.393*** (0.0795)	-0.312*** (0.0237)
Constant	6.693*** (0.165)	6.927*** (0.164)	8.472*** (0.236)
Observations	351	351	325
R-squared	0.516		
Number of Year	13	13	13
Country FE	Yes		
Hausman Test		Yes	
Prob		YES	
AR 2			Yes
Hansen test			Yes

Standard errors in parentheses

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table 7 presents the results for Model 4, utilizing the SYS-GMM model which includes two lagged variables of annual CO₂ emissions. The first lagged variable demonstrates a positive and statistically significant effect, with a coefficient of 0.158 ($p < 0.01$). This suggests that a 1% increase in CO₂ emissions from the previous period leads to a 0.158% increase in the current period's emissions. In contrast, the second lagged variable displays a negative and significant coefficient of -0.375 ($p < 0.01$), indicating a diminishing influence of earlier emissions over time, consistent with previous models. Energy Intensity consistently emerges as a significant determinant of CO₂ emissions across various models. For instance, the Fixed Effects model estimates a coefficient of 2.828 ($p < 0.01$), signifying that a 1% increase in energy intensity corresponds to a 2.828% increase in CO₂ emissions.

The Random Effects model and the SYS-GMM model yield similar influential results with coefficients of 2.668 and 2.897 respectively, reinforcing the strong linkage between energy intensity and emissions. The impact of Inflation on CO₂ emissions appears more subdued in Model 4 compared to previous iterations. In the Fixed Effects model, inflation leads to a 0.137% increase in emissions for every 1% increase in inflation, though this effect is only marginally significant ($p < 0.1$). Both the Random Effects and the SYS-GMM models show less significant impacts, indicating a weaker and inconsistent relationship when Political Stability is factored into the analysis. Urban Growth Rate remains a consistent predictor of CO₂ emissions, with all models indicating a positive association. The Fixed Effects model shows a coefficient of 0.331 ($p < 0.01$), the Random Effects model at 0.336 ($p < 0.01$), and the SYS-GMM model indicates a more pronounced effect at 0.495 ($p < 0.01$). These findings highlight the significant role urban growth plays in driving emissions, with an enhanced effect observed in the dynamic setting of the SYS-GMM model.

GDP Growth, however, shows varied impacts across models. It exhibits a positive but weakly significant coefficient of 0.167 ($p < 0.1$) in the Fixed Effects model, suggesting a modest increase in CO₂ emissions with GDP growth. The Random Effects model presents an insignificant positive coefficient, and the SYS-GMM model shows a minor negative and insignificant coefficient, indicating that the impact of GDP growth on emissions is not consistent and may depend on the inclusion of variables such as Political Stability. Lastly, Political Stability is introduced as a significant predictor in Model 4 and consistently shows a negative relationship with CO₂ emissions across all models. The coefficients suggest that

greater political stability is associated with reductions in CO2 emissions (-0.380 in the Fixed Effects model, -0.393 in the Random Effects model, and -0.312 in the SYS-GMM model, all significant at $p < 0.01$). This indicates that improved political stability likely supports better governance and more effective environmental policies, thus leading to lower emissions.

Table 8. Model 5

VARIABLES	(1) Fixed effects	(2) Random effects	(3) SYS-GMM
CO2 _{L1}			0.0975*** (0.0133)
CO2 _{L2}			-0.355*** (0.0267)
Energy_Intensity	3.163*** (0.161)	3.097*** (0.161)	3.126*** (0.173)
Inflation	-0.0156 (0.0676)	-0.0598 (0.0596)	-0.125 (0.104)
Urban_Growth_Rate	0.237*** (0.0715)	0.222*** (0.0714)	0.363*** (0.0313)
GDP_Growth	0.189** (0.0837)	0.127 (0.0794)	0.137 (0.0938)
Trade_Investment	-1.439*** (0.140)	-1.503*** (0.130)	-1.433*** (0.153)
Constant	5.179*** (0.143)	5.239*** (0.142)	7.359*** (0.319)
Observations	351	351	325
R-squared	0.605		
Number of Year	13	13	13
Country FE	Yes		
Hausman Test		Yes	
Prob		YES	
AR 2			Yes
Hansen test			Yes

Standard errors in parentheses
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table 8 outlines the findings from three econometric models—Fixed Effects, Random Effects, and System Generalized Method of Moments (SYS-GMM)—to analyze the relationship between annual CO2 emissions and various economic variables, focusing particularly on Trade Investment, alongside others such as Energy Intensity, Inflation, Urban Growth Rate, and GDP Growth. The SYS-GMM model incorporates two lagged variables of annual CO2 emissions. The first lag demonstrates a positive and statistically significant effect with a coefficient of

0.0975 ($p < 0.01$), indicating that a 1% increase in CO₂ emissions from the previous period leads to a 0.0975% rise in the current period's emissions.

Conversely, the second lag, exhibits a negative and significant coefficient of -0.355 ($p < 0.01$), suggesting a diminishing impact of past emissions over time. These findings confirm that while previous emissions influence current levels, their effect declines with time. Across all models, Energy Intensity remains a significant predictor of CO₂ emissions. The Fixed Effects model shows a coefficient of 3.163 ($p < 0.01$), indicating that each 1% increase in energy intensity results in a 3.163% increase in emissions. This is closely mirrored in the Random Effects model with a coefficient of 3.097 ($p < 0.01$) and in the SYS-GMM model with a coefficient of 3.126 ($p < 0.01$), reinforcing the strong, consistent positive relationship between energy intensity and CO₂ emissions.

Inflation presents an inconsistent and negative relationship with CO₂ emissions across all models in Model 5. The Fixed Effects model records a coefficient of -0.0156, and the Random Effects model notes -0.0598. The SYS-GMM model shows a more negative but still insignificant coefficient of -0.125. These findings indicate that inflation does not exert a consistent or substantial impact on CO₂ emissions when considering the role of Trade Investment. Urban Growth Rate consistently shows a significant and positive effect on CO₂ emissions across all models. In the Fixed Effects model, a 1% increase in the urban growth rate is associated with a 0.237% increase in emissions, evidenced by a coefficient of 0.237 ($p < 0.01$).

The Random Effects model and the SYS-GMM model show coefficients of 0.222 ($p < 0.01$) and 0.363 ($p < 0.01$) respectively, suggesting that urbanization significantly drives up emissions, with the SYS-GMM model indicating a potentially stronger effect when accounting for dynamic factors and endogeneity. GDP Growth has a mixed impact across the models. The Fixed Effects model suggests a modest but significant increase in emissions corresponding to economic growth, with a coefficient of 0.189 ($p < 0.05$). However, the Random Effects and SYS-GMM models show positive but insignificant coefficients of 0.127 and 0.137 respectively, indicating that the effect of GDP growth on emissions may vary and is not consistently significant across different models. Introduced in Model 5 as a critical variable, Trade Investment demonstrates a significant negative relationship with CO₂ emissions in all models. The Fixed Effects model shows a coefficient of -1.439 ($p < 0.01$), suggesting that higher trade investment correlates with a reduction in CO₂ emissions. This negative effect is slightly more pronounced in the Random Effects model with a coefficient of -1.503 ($p < 0.01$) and

remains significant in the SYS-GMM model at -1.433 ($p < 0.01$). These consistent findings across models suggest that increased trade investment likely contributes to emissions reduction, potentially through the adoption of cleaner technologies, improved production practices, or the impact of trade policies that favor environmental sustainability.

Table 9. Model 6

VARIABLES	(1) Fixed effects	(2) Random effects	(3) SYS-GMM
CO2 _{L1}			0.147*** (0.00817)
CO2 _{L2}			-0.377*** (0.0142)
Energy_Intensity	2.888*** (0.174)	2.601*** (0.180)	2.831*** (0.0426)
Inflation	0.0970 (0.0744)	0.0216 (0.0738)	-0.00615 (0.0393)
Urban_Growth_Rate	0.335*** (0.0797)	0.422*** (0.0836)	0.542*** (0.0316)
GDP_Growth	0.125 (0.0931)	0.0277 (0.0938)	-0.0610 (0.100)
Tech_Digital_Connectivity	-0.792*** (0.152)	-0.404*** (0.149)	-0.451*** (0.0899)
Constant	5.758*** (0.140)	6.198*** (0.134)	7.959*** (0.144)
Observations	351	351	325
R-squared	0.520		
Number of Year	13	13	13
Country FE	Yes		
Hausman Test		Yes	
Prob		YES	
AR 2			Yes
Hansen test			Yes

Standard errors in parentheses
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table 9 synthesizes results from three econometric models: Fixed Effects, Random Effects, and System Generalized Method of Moments (SYS-GMM), which assess the relationship between annual CO2 emissions and an array of economic and technological factors, with a particular focus on Tech Digital Connectivity. The models consistently demonstrate that the first lag of CO2 emissions positively influences current emissions by 0.147% per a 1% increase in the previous period, as per SYS-GMM analysis ($p < 0.01$). Conversely, the second lag shows a diminishing effect over time with a negative coefficient of -0.377 ($p < 0.01$). Energy Intensity

remains a robust driver across all models, indicating that a 1% increase in energy intensity correlates with increases of 2.888%, 2.601%, and 2.831% in CO₂ emissions across the Fixed Effects, Random Effects, and SYS-GMM models respectively.

Inflation, however, does not present a consistent impact across models, fluctuating between slight positive and insignificant negative influences, suggesting its minimal effect on CO₂ emissions when considering Tech Digital Connectivity. Urban Growth Rate consistently shows a significant and positive effect, increasing emissions by 0.335% to 0.542% across models, underscoring urbanization's strong impact on emissions. GDP Growth, while positive, remains statistically insignificant across models, indicating a less pronounced or consistent influence on emissions under these model settings. In contrast, Tech Digital Connectivity appears as a significant negative predictor, reducing CO₂ emissions across all models with coefficients ranging from -0.404 to -0.792, implying that advancements in digital connectivity can lead to reductions in emissions, potentially through efficiencies in production, smarter energy usage, or adoption of cleaner technologies.

The analysis conducted across six distinct models offers a comprehensive examination of the determinants of CO₂ emissions, factoring in a broad spectrum of economic, demographic, and technological variables. Using methodologies such as Fixed Effects, Random Effects, and System Generalized Method of Moments (SYS-GMM), the research provides robust insights into how these variables correlate with CO₂ emissions. The key findings from each model underline the consistent significance of some variables and the nuanced impacts of others. Energy Intensity emerges as a consistently significant and robust predictor of CO₂ emissions across all six models. The coefficients for Energy Intensity remain positive and statistically significant, typically ranging between 2.8 to 3.1 in SYS-GMM models, suggesting that higher energy consumption per unit of economic output is linked with increased CO₂ emissions. This persistent and strong relationship underscores the critical need for policies that focus on enhancing energy efficiency as a central strategy for emission reduction.

Urban Growth Rate consistently exhibits a significant positive correlation with CO₂ emissions across all models, indicating that emissions escalate with expanding urban populations due to increased energy demands. This effect is most pronounced in the SYS-GMM models, suggesting that rapid urbanization, especially in developing regions, is a major driver of rising emissions, thereby highlighting the importance of adopting sustainable urban development

practices. The relationship between Inflation and CO2 emissions varies across the models. In early models, a positive association suggests that higher inflation, potentially indicative of economic instability, might lead to inefficient energy use and higher emissions. However, in later models that include variables like Trade Investment and Tech Digital Connectivity, the impact of Inflation diminishes or even reverses, illustrating that its effect on emissions is complex and likely influenced by technological advancements or trade dynamics. GDP Growth shows mixed effects on CO2 emissions.

In some models, like the Fixed Effects in early iterations, there is a positive association, implying that economic expansion could lead to increased energy consumption and emissions. Conversely, in other models, including some SYS-GMM specifications, the impact of GDP Growth is minimal or negative, suggesting that the relationship might be moderated by factors such as technological improvements or sustainable practices. Global Integration in Model 1 displays a nuanced relationship with emissions; it is non-significant in simpler models but turns significantly negative in the SYS-GMM model. This indicates that greater global integration might reduce emissions, potentially through the international diffusion of cleaner technologies and stricter environmental standards. Financial Integration in Model 2 exhibits varying impacts. While not significant in simpler models, it shows a significant negative correlation in the SYS-GMM model, suggesting that deeper financial integration may facilitate investment in cleaner, more efficient technologies, thereby reducing emissions. Introduced in Model 4, Political Stability consistently correlates negatively with CO2 emissions across all models, suggesting that higher stability leads to lower emissions, likely due to more effective governance, stronger environmental policies, and better enforcement of regulations.

Trade Investment in Model 5 also consistently shows a negative correlation with emissions across all models, supporting the idea that increased trade investment, possibly through the spread of cleaner technologies and efficient production practices, can lead to emission reductions. Infrastructure Index in Model 3 is positively related to emissions in the Fixed and Random Effects models, indicating that unchecked infrastructure development may increase emissions. However, this relationship is not significant in the SYS-GMM model, suggesting that the impact may vary with economic development stages or infrastructure types. Finally, Tech Digital Connectivity in Model 6 has a significantly negative impact on emissions across all models, indicating that advancements in digital technology can greatly enhance energy efficiency, smarter urban planning, and the adoption of innovative technologies, thereby reducing the environmental impacts of economic activities.

The comprehensive analysis conducted across Models 1 to 6 offers robust insights into the determinants of CO₂ emissions, revealing the complexities of their interactions with various economic, political, and technological factors. Energy Intensity and Urban Growth Rate are identified as consistent and significant drivers of emissions. These findings underscore the urgency of developing targeted policies that not only enhance energy efficiency but also manage urban expansion in a sustainable manner. On the other hand, variables such as Political Stability, Trade Investment, and Tech Digital Connectivity demonstrate significant negative relationships with emissions, highlighting their potential roles in environmental mitigation. The effects of Inflation and GDP Growth on emissions appear to be context-dependent, indicating that their impacts are influenced by the broader economic, technological, and policy landscape. These insights contribute to a deeper understanding of how various factors interplay to shape environmental outcomes, providing valuable guidance for policymakers and stakeholders committed to advancing sustainable development.

5. Conclusion, policy implications and future research agenda

This study undertakes a comprehensive examination of the socio-economic and environmental factors influencing carbon dioxide (CO₂) emissions, with a focus on how global integration, financial integration, trade investment, technological and digital connectivity, infrastructure, and other macroeconomic variables such as GDP growth, energy intensity, and urbanization contribute to the overall carbon footprint. Using robust datasets from the Asia Regional Integration Centre and the World Bank, and employing advanced econometric techniques, including Fixed Effects, Random Effects, and System Generalized Method of Moments (SYS-GMM) models, the research provides nuanced insights into the determinants of CO₂ emissions. The results consistently demonstrate the significant role of energy intensity in driving CO₂ emissions across all models. The positive and robust relationship between energy intensity and emissions underscores the critical need for policy interventions aimed at improving energy efficiency and transitioning to cleaner energy sources.

Urban growth rate also emerged as a significant and consistent predictor of CO₂ emissions, highlighting the environmental challenges posed by rapid urbanization. These findings suggest that urban planning and the promotion of sustainable urban development practices should be central to climate action strategies. In contrast, technological and digital connectivity was found to have a significant negative impact on CO₂ emissions, indicating that advancements

in digital technologies can contribute to reducing emissions through increased efficiency, smarter energy usage, and the adoption of cleaner technologies. This finding supports the argument that digital transformation, if properly harnessed, can play a crucial role in mitigating climate change. The study also reveals mixed results for other macroeconomic variables such as GDP growth and inflation. While GDP growth showed a marginal and inconsistent impact on emissions across different models, inflation's effect varied, with significant positive impacts in some models but negligible in others.

These results suggest that the relationship between economic growth, inflation, and emissions is complex and context-dependent, requiring tailored policy responses that consider the specific economic environment of each country or region. Notably, the role of global and financial integration in influencing CO₂ emissions was found to be context dependent. While global integration showed a negative and significant effect in the SYS-GMM model, suggesting that higher integration might facilitate the adoption of sustainable practices and technologies, financial integration showed mixed results, with some models indicating a potential for emissions reduction through more sustainable investment practices. These findings highlight the dual-edged nature of economic globalization, where both opportunities and risks for environmental sustainability coexist, necessitating careful and strategic policy design to harness the benefits while mitigating the risks. Overall, this research contributes to the existing literature by providing empirical evidence on the complex and multifaceted relationships between socio-economic factors and CO₂ emissions.

The findings underscore the importance of adopting a multidimensional approach to environmental policy, one that integrates considerations of economic development, technological advancement, and global interconnectedness. Policymakers are urged to consider these dynamics in their efforts to reduce carbon emissions and promote sustainable development. By addressing the key drivers of emissions identified in this study, it is possible to formulate more effective and targeted strategies that align economic growth with environmental sustainability, thereby contributing to global efforts to mitigate the impacts of climate change.

The findings of this study yield several important policy implications that can guide efforts to reduce carbon dioxide (CO₂) emissions while promoting sustainable economic development. First and foremost, the strong and consistent positive relationship between energy intensity and CO₂ emissions across all models underscores the critical need for policies that enhance energy

efficiency. Governments should prioritize the adoption of energy-saving technologies and facilitate the transition to low-carbon energy sources through targeted investments in renewable energy infrastructure and the promotion of energy-efficient industrial practices. Tightening energy efficiency standards, particularly in energy-intensive sectors, is essential to achieving significant reductions in carbon emissions.

Furthermore, the significant impact of urban growth on CO₂ emissions highlights the environmental challenges associated with rapid urbanization. Policymakers should emphasize sustainable urban planning and development strategies that minimize the environmental footprint of expanding urban areas. This includes promoting green building practices, improving public transportation systems to reduce fossil fuel dependency, and fostering the development of smart cities that leverage digital technologies to optimize energy use and reduce emissions. Such policies are crucial for creating resilient urban environments capable of adapting to the challenges posed by climate change. The study also reveals that technological and digital connectivity has a significant negative impact on CO₂ emissions, suggesting that advancements in digital technologies can be instrumental in reducing emissions.

Policymakers should encourage the widespread adoption of digital solutions that enhance energy efficiency, such as smart grids and telecommuting, and should invest in digital infrastructure to support the transition to renewable energy. Ensuring that these technological advancements are accessible, particularly in developing regions, will be key to maximizing their potential for emissions reduction. The mixed findings regarding the impact of global and financial integration on CO₂ emissions indicate that these factors can influence environmental outcomes in both positive and negative ways. Policymakers should seek to maximize the environmental benefits of global integration by fostering international cooperation on climate policies, facilitating the transfer of clean technologies, and aligning trade and investment policies with environmental objectives.

Financial integration should be guided by sustainable finance principles, encouraging investments in green technologies and infrastructure, while harmonizing environmental regulations across borders to prevent the creation of pollution havens. Additionally, the variable impact of inflation on CO₂ emissions suggests that economic policies must consider the environmental consequences of inflationary pressures. Policymakers should be cautious in managing inflation, ensuring that short-term economic measures do not undermine long-term environmental goals. In high-inflation scenarios, targeted interventions may be necessary to

mitigate adverse effects on emissions, such as promoting energy-efficient technologies or providing subsidies for clean energy adoption.

Lastly, the study's findings on the inconsistent relationship between GDP growth and CO₂ emissions highlight the need for growth strategies that decouple economic expansion from carbon emissions. Policymakers should focus on promoting sectors that contribute to economic growth while minimizing environmental impact, such as renewable energy, green technology, and sustainable agriculture. By integrating sustainability criteria into economic planning and development policies, governments can ensure that economic progress does not come at the expense of environmental health. These policy implications provide actionable insights for crafting more targeted and effective strategies to address the complex challenges of climate change.

Based on the findings and limitations of this study, several avenues for future research emerge that could further enhance our understanding of the relationship between socio-economic factors and CO₂ emissions. First, given the mixed results regarding the impact of global and financial integration on CO₂ emissions, future research could explore these relationships in greater detail across different regions and economic contexts. Comparative studies that examine the varying effects of global integration in developed versus developing countries could provide more nuanced insights into how globalization influences environmental outcomes. Additionally, longitudinal studies that track changes in these relationships over time could help identify whether the effects of global integration evolve as countries move through different stages of economic development.

Second, the significant influence of urban growth on CO₂ emissions suggests a need for more granular research into the specific mechanisms through which urbanization drives emissions. Future studies could explore the role of urban planning, infrastructure quality, and public transportation systems in moderating the environmental impact of urban growth. Case studies of cities that have successfully mitigated the environmental impact of rapid urbanization could offer valuable lessons for policymakers in other regions. Third, the study highlights the potential of technological and digital connectivity to reduce CO₂ emissions, yet the mechanisms behind this relationship remain underexplored. Future research could delve into how specific digital technologies, such as smart grids, artificial intelligence, and the Internet of Things (IoT), contribute to emissions reduction.

Moreover, examining the digital divide between countries and its implications for global emissions could provide important insights into how digital infrastructure investments can be optimized for environmental benefits. Fourth, the inconsistent impact of GDP growth and inflation on CO₂ emissions suggests that these relationships are complex and potentially moderated by other variables. Future research could investigate how different economic policies, such as fiscal stimulus measures, monetary policy, and trade policies, interact with GDP growth and inflation to influence emissions. Additionally, research could explore the role of economic structure, such as the proportion of the economy dedicated to manufacturing versus services, in shaping the relationship between economic growth and emissions.

Lastly, this study's focus on macroeconomic variables offers a broad perspective, but future research could benefit from integrating microeconomic data to examine how firm-level decisions, consumer behavior, and technological adoption directly impact CO₂ emissions. Such research could provide more targeted insights into the specific actions that companies and individuals can take to contribute to emissions reduction, thereby complementing the macro-level findings with actionable recommendations at the micro level. By pursuing these research directions, scholars can contribute to a more comprehensive understanding of the complex dynamics between socio-economic factors and CO₂ emissions, ultimately supporting the development of more effective and context-sensitive environmental policies.

CRedit authorship contribution statement

Amar Rao: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

Vishal Dagar: Writing – review & editing, Supervision, Project administration, Methodology

Declaration of competing interest

None

Data availability

The data that has been used is publicly available.

Declaration of generative AI and AI-assisted technologies in the writing process.

During the preparation of this work the author(s) used chatGPT4 in order to improve the grammar and readability of the manuscript. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the published article.

Appendix

Table A1. Variance Inflation Factor (VIF) Analysis interpretation for Model 1

Variable	VIF	1/VIF	Interpretation
Global Integration	1.69	0.593185	Low multicollinearity; acceptable for analysis.
Inflation	1.40	0.714774	Low multicollinearity; acceptable for analysis.
Urban Growth Rate	1.31	0.762126	Low multicollinearity; acceptable for analysis.
Energy Intensity	1.12	0.890366	Very low multicollinearity; excellent for analysis.
GDP Growth	1.05	0.950706	Very low multicollinearity; excellent for analysis.

Mean VIF: 1.31 - Indicates overall low multicollinearity among predictors, suggesting that the model's estimates are reliable, and each predictor largely provides unique information without substantial overlap with others in the model. This is beneficial for the robustness of regression analysis findings.

Table A2. Variance Inflation Factor (VIF) Analysis interpretation for Model 2

Variable	VIF	1/VIF	Interpretation
Financial Integration	1.32	0.758631	Low multicollinearity; acceptable for analysis.
Inflation	1.30	0.770431	Low multicollinearity; acceptable for analysis.
Urban Growth Rate	1.21	0.829679	Low multicollinearity; acceptable for analysis.
GDP Growth	1.05	0.950018	Very low multicollinearity; excellent for analysis.
Energy Intensity	1.01	0.989253	Very low multicollinearity; excellent for analysis.

Mean VIF: 1.18 - Indicates overall very low multicollinearity among predictors, enhancing the reliability of the regression model's estimates. Each predictor contributes unique information, minimizing concerns over overlapping explanatory power. This model is well-suited for robust statistical analysis

Table A3. Variance Inflation Factor (VIF) Analysis interpretation for Model 3

Variable	VIF	1/VIF	Interpretation
Inflation	1.35	0.739148	Low multicollinearity; acceptable for analysis.
Infrastructure Index	1.24	0.806765	Low multicollinearity; acceptable for analysis.
Urban Growth Rate	1.13	0.883588	Very low multicollinearity; excellent for analysis.
GDP Growth	1.06	0.947209	Very low multicollinearity; excellent for analysis.
Energy Intensity	1.03	0.970987	Very low multicollinearity; excellent for analysis.

Mean VIF: 1.16 - Indicates overall very low multicollinearity among the predictors, enhancing the statistical robustness of your regression model. This low mean VIF suggests that each variable in the model provides unique information without substantial overlap, ideal for accurate and reliable regression analysis outcomes.

Table A4. Variance Inflation Factor (VIF) Analysis interpretation for Model 4

Variable	VIF	1/VIF	Interpretation
Political Stability	1.42	0.703068	Low multicollinearity; acceptable for analysis.
Urban Growth Rate	1.35	0.741401	Low multicollinearity; acceptable for analysis.
Inflation	1.22	0.817713	Low multicollinearity; acceptable for analysis.
GDP Growth	1.05	0.950764	Very low multicollinearity; excellent for analysis.
Energy Intensity	1.03	0.967780	Very low multicollinearity; excellent for analysis.

Mean VIF: 1.22 - Indicates overall very low multicollinearity among the predictors, suggesting that the model is statistically robust. This low mean VIF confirms that each variable provides unique information without significant overlap, which is ideal for conducting reliable and accurate regression analysis.

Table A5. Variance Inflation Factor (VIF) Analysis interpretation for Model 5

Variable	VIF	1/VIF	Interpretation
Trade Investment	1.36	0.734840	Low multicollinearity; acceptable for analysis.
Urban Growth Rate	1.28	0.782432	Low multicollinearity; acceptable for analysis.
Inflation	1.20	0.833142	Low multicollinearity; acceptable for analysis.
Energy Intensity	1.11	0.899782	Very low multicollinearity; excellent for analysis.
GDP Growth	1.05	0.948312	Very low multicollinearity; excellent for analysis.

Mean VIF: 1.20 - Indicates overall very low multicollinearity among the predictors, suggesting that the regression model is statistically robust. This low mean VIF implies that each variable in the model provides unique information without significant overlap, which is ideal for conducting reliable and accurate regression analysis.

Table A6. Variance Inflation Factor (VIF) Analysis interpretation for Model 6

Variable	VIF	1/VIF	Interpretation
Tech Digital Connectivity	1.60	0.623287	Low multicollinearity; acceptable for analysis.
Inflation	1.36	0.736811	Low multicollinearity; acceptable for analysis.
Urban Growth Rate	1.29	0.774613	Low multicollinearity; acceptable for analysis.
GDP Growth	1.09	0.920465	Very low multicollinearity; excellent for analysis.
Energy Intensity	1.03	0.972456	Very low multicollinearity; excellent for analysis.

Mean VIF: 1.27 - Indicates overall very low multicollinearity among the predictors, enhancing the statistical robustness of your regression model. This low mean VIF suggests that each variable in the model provides unique information without significant overlap, which is ideal for conducting reliable and accurate regression analysis.

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