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The Mediating Role of Globalization in the Nexus Between CO₂ Emissions, GHGs, and Economic Growth

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Abstract

Purpose - This study investigates the mediating role of globalization in the relationship between carbon dioxide (CO₂) emissions, greenhouse gas (GHG) emissions, and economic growth in G20 countries. It seeks to determine whether globalization can transform environmental pressures into drivers of sustainable economic performance.

Design/methodology/approach - The analysis relies on balanced panel data from 20 G20 countries covering the period 2010–2024. Advanced panel econometric techniques are employed to estimate direct and indirect (mediating) effects, while controlling for cross-country heterogeneity and time-specific effects.

Findings - The empirical results reveal that CO₂ and GHG emissions exert a negative but statistically insignificant direct effect on economic growth. However, globalization has a positive and significant impact on growth and fully mediates the relationship between emissions and economic performance. Specifically, higher levels of globalization reduce the adverse growth effects of emissions by facilitating technology transfer, cleaner production processes, and access to environmentally efficient markets.

Research limitations/implications - The study is limited to G20 economies and does not account for country-specific environmental regulations or sectoral emission structures, which may influence the magnitude of the effects.

Practical implications - Policymakers should integrate globalization-oriented strategies with environmental policies to enhance green technology diffusion and sustain long-term economic growth.

Originality/value - This study is among the first to empirically demonstrate the mediating role of globalization in the emissions–growth nexus within G20 countries over a recent and extended period, offering a dynamic perspective absent from prior studies.

From a Decision Sciences perspective, this study provides analytical evidence that supports strategic policymaking by helping decision-makers evaluate trade-offs between economic growth and environmental sustainability under conditions of global interdependence and uncertainty.

Keywords: CO₂ emissions; Greenhouse gas emissions; Globalization; Economic growth; G20.

JEL Classifications : F43, O44, Q43, Q56

1. Introduction

Globalization, defined as a process of economic, social, and institutional integration across countries, has profoundly reshaped development trajectories and interactions among nations. While globalization has stimulated economic growth through trade liberalization, capital mobility, and technological diffusion, it has simultaneously intensified environmental pressures, particularly in terms of carbon dioxide (CO₂) and greenhouse gas (GHG) emissions. These emissions are closely linked to industrial expansion, energy consumption, and production patterns that have accelerated in the context of global economic integration. As emphasized by Sachs (2015), contemporary growth models must be reassessed in light of escalating environmental challenges, notably climate change.

The relevance of this issue is particularly pronounced for G20 countries, which collectively account for a substantial share of global economic output and global emissions. Understanding how globalization influences both environmental outcomes and economic performance is therefore crucial for designing balanced development strategies. Previous studies, such as Dietz and O'Neill (2016), suggest that globalization can act as a double-edged sword: it may exacerbate environmental degradation while also facilitating access to cleaner technologies and international environmental standards. Through international trade and investment, countries may benefit from technology transfer and innovation, potentially reducing emission intensity and improving environmental efficiency.

However, globalization also raises concerns related to emissions offshoring, whereby polluting industries relocate to countries with weaker environmental regulations (Zhang et al., 2020). This dynamic highlights ethical and regulatory challenges, as well as asymmetries in countries' capacities to manage environmental externalities. In line with Piketty (2020), globalization may amplify inequalities not only in income distribution but also in environmental responsibility and resilience, reinforcing the need for coordinated international policy frameworks.

Despite an extensive body of literature examining globalization, emissions, and economic growth, several important research gaps remain. First, the mediating role of globalization in the relationship between environmental degradation and economic growth has received limited empirical investigation. Second, many existing studies focus on individual countries or restricted regional samples, thereby overlooking a comprehensive comparative analysis within the G20 context. Third, prior research often emphasizes direct relationships between emissions and growth without considering the complex transmission mechanisms through which globalization may influence these interactions.

The primary motivation of this study is to address these limitations by examining whether globalization serves as a catalyst for sustainable economic development or, alternatively, amplifies environmental degradation through intensified production and consumption patterns. This research contributes to the existing literature by developing an integrated analytical framework that captures the multidimensional interactions between globalization, environmental performance, and economic growth. By employing panel econometric techniques and recent longitudinal data, the study provides robust empirical evidence on the dynamic role of globalization in shaping environmental-economic trade-offs.

The originality of this study lies in its explicit modeling of globalization as a mediating mechanism in the relationship between CO₂ emissions, GHG emissions, and economic growth within a unified G20 framework over the period 2010–2024, an approach that extends beyond prior studies that primarily focus on direct causal effects or limited geographical coverage.

This study empirically investigates how globalization mediates the relationship between CO₂ emissions, GHG emissions, and economic growth across 20 G20 countries during the period 2010–2024. The analysis evaluates whether globalization mitigates or intensifies the economic consequences of environmental degradation, thereby offering new insights into the sustainability of global economic integration.

From a Decision Sciences perspective, this study provides analytical evidence that supports strategic policymaking by helping decision-makers evaluate trade-offs between economic growth and environmental sustainability under conditions of global interdependence and uncertainty.

By integrating environmental and economic dimensions within a decision-oriented analytical framework, this research generates policy-relevant implications for aligning globalization strategies with sustainable development objectives. The findings aim to assist policymakers in designing coordinated economic and environmental policies that leverage globalization to promote cleaner growth pathways while recognizing the shared responsibilities of G20 countries.

The remainder of this paper is organized as follows. Section 2 reviews the relevant literature and develops the research hypotheses. Section 3 presents the methodology and data. Section 4 discusses the empirical results. Section 5 concludes by summarizing the main findings and outlining policy implications.

2. Literature Review and Background Theory

2.1 Background Theory

The relationship between economic growth, environmental degradation, and globalization is rooted in several well-established economic theories that jointly justify the choice of variables and the empirical framework adopted in this study.

First, the neoclassical growth theory posits that economic growth is driven by capital accumulation, labor, and technological progress, as formalized in the augmented Solow model developed by Robert Solow (Solow, 1999). The aggregate production function is typically expressed as:

$$Y(t) = K(t)^\alpha A(t) L(t)^{1-\alpha},$$

where $Y(t)$ denotes output, $K(t)$ denotes capital, $L(t)$ denotes labor, and $A(t)$ denotes the level of technology. Capital accumulation follows:

$$K'(t) = sY(t) - \delta K(t).$$

Environmental quality enters this framework indirectly, as pollution and resource depletion negatively affect productivity, human capital, and long-term growth potential. This can be captured by introducing an environmental damage function into production (Nordhaus, 1994; Stern, 2004):

$$Y(t) = K(t)^\alpha A(t) L(t)^{1-\alpha} e^{-\theta E(t)},$$

where $E(t)$ represents emissions (e.g., CO₂ or GHG) and $\theta > 0$ measures the negative impact of environmental degradation on output. Excessive carbon dioxide (CO₂) and greenhouse gas (GHG) emissions may therefore reduce output by increasing health costs, damaging ecosystems, and constraining productive capacity.

Second, the Environmental Kuznets Curve (EKC) hypothesis, initially associated with Simon Kuznets (Kuznets, 1955) and empirically extended by Grossman and Krueger (1995), suggests a non-linear relationship between environmental degradation and economic growth. In the early stages of development, economic growth is associated with rising emissions due to industrialization and energy-intensive production. Beyond a certain income threshold, further growth leads to improved environmental quality as economies shift toward cleaner technologies and stronger environmental regulations. The EKC is commonly specified as:

$$E_t = \beta_0 + \beta_1 Y_t + \beta_2 Y_t^2 + \varepsilon_t,$$

where E_t denotes environmental degradation, and Y_t denotes income per capita. The inverted U-shape holds if $\beta_1 > 0$ and $\beta_2 < 0$ (Dinda, 2004; Stern, 2004). This theoretical framework supports the inclusion of CO₂ and GHG emissions as core explanatory variables of economic growth.

Third, the role of globalization is theoretically grounded in international trade theory and endogenous growth models, particularly the work of Paul Romer (Romer, 1990). In this framework, technological progress evolves according to:

$$A'(t) = \delta A(t)^\phi G(t)^\gamma,$$

where $G(t)$ represents globalization (e.g., trade openness or FDI), and $\gamma > 0$ captures the effect of globalization on knowledge diffusion and innovation. Empirical studies confirm that openness enhances productivity through technology transfer and innovation (Frankel & Romer, 1999). Globalization can therefore influence economic growth directly, while simultaneously shaping environmental outcomes through the diffusion of cleaner production processes and environmental standards.

However, globalization may also generate adverse environmental effects through the pollution haven hypothesis, formalized by Brian Copeland and M. Scott Taylor (Copeland & Taylor, 2004), which argues that firms relocate polluting activities to countries with lax environmental regulations. This mechanism can be represented as:

$$E(t) = \phi Y(t) + \psi G(t),$$

where $\psi > 0$ reflects the potential increase in emissions due to pollution relocation effects (Cole, 2004; Shahbaz et al., 2024). This dual role justifies modeling globalization as a mediating variable, rather than merely an exogenous determinant.

2.2 Literature Review and Hypothesis Development

2.2.1 The Effect of CO₂ Emissions on Economic Growth

The relationship between carbon dioxide (CO₂) emissions and economic growth is complex and multifaceted, reflecting both positive and negative interactions that influence sustainable development. Several recent empirical studies have explored this dynamic, revealing that while CO₂ emissions may initially stimulate economic growth through industrialization and increased production, they also generate environmental consequences that undermine this same growth

Apergis and Pinar (2021) explored the relationship between CO₂ emissions and economic growth in European Union countries, concluding that emissions are initially correlated with an increase in gross domestic product (GDP), but that this relationship becomes unfavorable when emissions exceed a certain threshold, leading to increasing environmental and economic costs. Furthermore, Shahbaz et al. (2024) analyzed the impacts of CO₂ emissions on the industrial sector in Southeast Asia. The results show that countries that experienced high levels of industrialization also saw an increase in their CO₂ emissions, which initially boosted their economic growth. However, the research highlights that this growth is often associated with a deterioration in living conditions and the environment, making the sustainability of development uncertain. Another study by Hossain et al. (2024) examined the effects of CO₂ emissions on economic growth in Middle Eastern and North African countries. The authors found that, although emissions are linked to an increase in GDP, emission reduction policies can also generate long-term benefits by encouraging innovation and economic diversification, suggesting that the transition to cleaner technologies could provide growth opportunities. Finally, Yavuz et al. (2024) focused on the effects of CO₂ emissions on public health and their indirect impact on economic growth. The results showed that healthcare costs resulting from air pollution can hamper economic growth by increasing public spending and decreasing worker productivity. These studies highlight that CO₂ emissions can have ambivalent effects on economic growth, where short-term benefits can clash with long-term environmental and health costs. Thus, the following hypothesis can be formulated:

H1: Carbon dioxide emissions have a significant impact on economic growth.

2.2.2 The Effect of Greenhouse Gas Emissions on Economic Growth

The effect of greenhouse gas (GHG) emissions on economic growth is a central topic in contemporary economics, generating growing interest in its long-term implications. Several recent empirical studies highlight the complex dynamics that exist between these variables. Ozturk et al. (2022) analyzed the relationship between GHG emissions and economic growth in emerging countries. The results indicate that increased emissions, often linked to rapid industrialization, can initially stimulate economic growth by creating jobs and increasing industrial production. However, this dynamic can generate adverse environmental effects, leading to natural resource degradation and ecological imbalances that, in the long run, hamper growth. Furthermore, Ali et al. (2023) focused on the impact of GHG emissions

on the agricultural sector in several African countries. The results show that rising GHG levels harm agricultural productivity, leading to significant economic losses, particularly in regions vulnerable to climate change. This phenomenon highlights the vulnerability of agriculture-dependent economies to the impacts of GHG emissions, which can reduce yields and increase the costs of managing environmental crises. Furthermore, Lee et al. (2024) examined the effects of emission reduction policies in the context of G20 countries. Their study reveals that, although these policies may appear to hinder economic growth in the short term, they actually promote technological innovation and the creation of new green sectors. Investments in clean technologies, for example, can generate jobs and stimulate growth, thus offsetting the economic losses caused by emission reductions. Pham and Tuan (2022), explored the relationship between GHG emissions and economic competitiveness. The results suggest that countries that adopt proactive emission reduction strategies can strengthen their international market position, thereby attracting foreign investment and improving their long-term economic growth. The authors emphasize that countries that neglect environmental issues risk facing trade sanctions and limited access to international markets, which could hamper their growth. This research shows that greenhouse gas emissions have an ambivalent relationship with economic growth, with positive effects occurring in the short term but negative consequences often occurring in the long term. Similarly, Adzawla et al. (2019) used aggregated panel data for the period 1970–2012 to estimate a vector autoregressive model as well as an ordinary least squares regression. The results reveal a short-run relationship between economic growth and environmental quality, although no clear turning point for greenhouse gases is observed. In the long run, a monotonically decreasing relationship exists between economic growth and environmental quality. Notably, this study highlights that global greenhouse gas emission levels have a long-run impact on economic growth in SSA countries. We conclude that a global effort is essential to introduce innovations and technologies that increase production while reducing GHG emissions, to ensure that economic growth contributes to improving environmental quality. The lack of effective emissions management can lead to substantial economic costs related to environmental disasters and resource degradation. Therefore, the following hypothesis can be formulated:

H2: Greenhouse gas emissions have a significant impact on economic growth.

2.2.3 The Mediating Effect of Globalization Between CO₂ and Greenhouse Gas Emissions and Economic Growth

Globalization plays a crucial role in the dynamics between carbon dioxide (CO₂) emissions, greenhouse gases (GHGs), and economic growth, acting as both a catalyst and a moderator of these interactions. As economies become more globally integrated, cross-border trade and investment can lead to increased CO₂ emissions due to increased industrialization and rising energy consumption. However, this globalization also opens up opportunities for the adoption of cleaner technologies and sustainable practices. Liu et al. (2020) showed that globalization, by facilitating trade and encouraging foreign investment, can initially increase CO₂ emissions. However, the study also highlighted that globalization provides access to technological innovations and improved environmental practices, which can mitigate the adverse effects of emissions on the environment and promote sustainable economic growth. Furthermore, research by Wang et al. (2023) examined how globalization influences the adoption of environmental policies in developing countries. The results showed that countries

integrated into global trade are often subject to international pressure, which encourages them to adopt stricter environmental standards. This has led to a shift towards more sustainable economic practices, strengthening the countries' ability to grow economically while reducing their carbon footprint. Another study by Shahbaz et al. (2024) analyzed how globalization acts as a mediator in the relationship between GHG emissions and economic growth in developing countries. The results indicate that these countries, in response to global demand for sustainable products, adopt innovative environmental policies. This dynamic fosters innovation and the transition to more environmentally friendly economic practices, which can ultimately boost economic growth while reducing GHG emissions. Furthermore, Zaman and Yu (2024) explored the effects of globalization on GHG emissions, finding that globalization allowed countries to share green technologies and best practices, which led to lower emissions per unit of GDP. Furthermore, a study by Balçı et al. (2025) found that integration into the global economy facilitates access to financing for renewable energy projects, thereby strengthening countries' capacity to invest in sustainable infrastructure. This research shows that globalization can act as a mediator between CO₂ emissions, GHGs, and economic growth, fostering economic transformations that combine development and sustainability. Thus, we can formulate the following hypothesis:

H3: Globalization exerts a significant mediating effect between carbon dioxide emissions, greenhouse gases, and economic growth.

3. Methodology, Data, and Empirical Strategy

3.1 Data

This study employs annual panel data for 20 G20 countries over the period 2010–2024, yielding a balanced panel of 300 observations (20 countries × 15 years). Annual frequency is adopted to ensure consistency across countries and to capture medium- to long-term macroeconomic and environmental dynamics. The data are obtained from the Global Economy Database, which provides harmonized and internationally comparable indicators.

Economic growth is measured by real GDP growth rate (EG), reflecting changes in economic performance over time. Environmental degradation is proxied by carbon dioxide emissions (CO₂), measured in metric tons per capita, and greenhouse gas emissions (GHGs), expressed in CO₂-equivalent terms, capturing broader climate-related externalities.

Globalization (GLOB) is measured using a composite globalization index that reflects economic integration through trade, capital flows, and international linkages. This variable captures the degree to which economies are integrated into the global system.

Several control variables are included to avoid omitted variable bias. Inflation (INF) is incorporated to account for macroeconomic stability, as high inflation distorts investment decisions and economic growth (Fischer, 1993). Unemployment (UNEMP) reflects labor market conditions and productive capacity utilization, which directly influence output growth. Regulatory Quality (REGQ) captures

institutional effectiveness and the ability of governments to design and implement sound policies, a key determinant of both economic performance and environmental regulation (Coyle et al., 2011).

All variables are transformed into natural logarithms where appropriate to reduce heteroskedasticity and allow elasticity-based interpretations.

3.2 Methodological Framework

Panel data methodology is particularly suitable for this analysis as it allows the examination of both cross-country heterogeneity and time dynamics. By combining cross-sectional and temporal dimensions, panel data models control for unobserved country-specific effects that may bias the estimated relationships (Baltagi et al., 2005; Wooldridge, 2010).

Two main panel estimators are considered: the fixed-effects model (FEM) and the random-effects model (REM). The fixed-effects approach controls for time-invariant unobserved heterogeneity that may be correlated with explanatory variables, while the random-effects model assumes that such effects are uncorrelated. The Hausman test is employed to determine the most appropriate specification.

3.3 Mediation Analysis: Baron and Kenny Approach

To empirically examine the mediating role of globalization, this study follows the classical mediation framework proposed by Baron and Kenny (1986), explicitly implemented through a sequence of regression steps expressed in a cohesive manner. First, economic growth is regressed on CO₂ emissions and GHG emissions in order to assess their direct effects on the dependent variable. Second, globalization is regressed on CO₂ emissions and GHG emissions to determine whether environmental variables significantly influence the mediator. Third, economic growth is regressed on globalization to evaluate the direct effect of the mediator on growth. Fourth, economic growth is regressed simultaneously on both emissions variables and globalization to capture their joint effects within a unified specification. Finally, mediation is confirmed if the coefficients associated with CO₂ and GHG emissions decrease in magnitude or lose statistical significance following the inclusion of globalization, while the coefficient of globalization remains statistically significant. This structured approach enables a clear identification of indirect effects and ensures methodological transparency.

Although the mediation approach of Baron and Kenny (1986) has been criticized for its relatively low statistical power and its reliance on sequential significance testing compared to bootstrapping methods, it is adopted in this study due to the short panel timeframe (T = 15), which may render bootstrap resampling procedures unstable and less reliable in small-T panel settings.

3.4 Model $GLOB_{it}$

The model is expressed as follows:

$$EG_{it} = \alpha_0 + \alpha_1 CO2_{it} + \alpha_2 INV_{it} + \alpha_3 Inflation_{it} + \alpha_4 UNMP_{it} + \alpha_5 RQ_{it} + \varepsilon_{it} , \quad (1)$$

$$EG_{it} = \alpha_0 + \alpha_1 GHGE_{it} + \alpha_2 INV_{it} + \alpha_3 Inflation_{it} + \alpha_4 UNMP_{it} + \alpha_5 RQ_{it} + \varepsilon_{it} , \quad (2)$$

$$EG_{it} = \alpha_0 + \alpha_1 GLOB_{it} + \alpha_2 INV_{it} + \alpha_3 Inflation_{it} + \alpha_4 UNMP_{it} + \alpha_5 RQ_{it} + \varepsilon_{it}, \quad (3)$$

$$GLOB_{it} = \alpha_0 + \alpha_1 CO2_{it} + \alpha_2 INV_{it} + \alpha_3 Inflation_{it} + \alpha_4 UNMP_{it} + \alpha_5 RQ_{it} + \varepsilon_{it}, \quad (4)$$

$$GLOB_{it} = \alpha_0 + \alpha_1 GHGE_{it} + \alpha_2 INV_{it} + \alpha_3 Inflation_{it} + \alpha_4 UNMP_{it} + \alpha_5 RQ_{it} + \varepsilon_{it}, \quad (5)$$

The unified specifications are expressed as:

$$EG_{it} = \alpha_0 + \alpha_1 CO2_{it} + \alpha_2 GLOB_{it} + \alpha_3 INV_{it} + \alpha_4 Inflation_{it} + \alpha_5 UNMP_{it} + \alpha_6 RQ_{it} + \varepsilon_{it}, \quad (6)$$

$$EG_{it} = \alpha_0 + \alpha_1 GHGE_{it} + \alpha_2 GLOB_{it} + \alpha_3 INV_{it} + \alpha_4 Inflation_{it} + \alpha_5 UNMP_{it} + \alpha_6 RQ_{it} + \varepsilon_{it}, \quad (7)$$

where EG_{it} denotes the economic growth of country i at year t ; $CO2_{it}$ represents Carbon dioxide emissions of country i at year t ; $GHGE_{it}$ refers to greenhouse emissions of country i at year t ; $GLOB_{it}$ represents the globalization index of country i at year t ; INV_{it} represents the investment rate of country i at year t ; $Inflation_{it}$ represents the inflation rate of country i at year t ; $UNMP_{it}$ represents the unemployment rate of country i at year t , and RQ_{it} represents the degree of regularity quality of country i at year t .

3.5 Variable Definitions

Economic growth is measured by gross domestic product (GDP), which remains the most widely used indicator for assessing the overall economic performance of a country. Both nominal and real GDP are commonly employed to evaluate economic growth and the productive capacity of an economy, as emphasized by Dietz and O'Neill (2016). Furthermore, CO₂ emissions are measured as emissions per unit of GDP, allowing for the assessment of energy efficiency and the environmental intensity of economic activity. This indicator captures the relationship between economic output and environmental pressure, an issue widely discussed in the literature on sustainable development, including the work of Hepburn et al. (2020). Similarly, greenhouse gas (GHG) emissions are measured as total GHG emissions per unit of GDP, which provides an additional measure of environmental performance and energy efficiency in relation to economic production. This metric helps evaluate the environmental consequences of economic activity and the progress of countries toward climate mitigation objectives.

In addition, globalization is measured using the KOF Globalization Index, a comprehensive indicator that captures economic, social, and political dimensions of globalization. This index was developed by Dreher (2006) and has become one of the most widely used measures for assessing the degree of integration of countries into the global economy. Investment is another key variable in the analysis and is defined as the allocation of financial or material resources to assets with the objective of generating future returns. In classical macroeconomic theory, Keynes (1936) identified investment as a fundamental component of aggregate demand, directly influencing economic activity and growth. More recently, Mazzucato (2018) emphasized the importance of investment in innovation and sustainable technologies to support the transition toward a more sustainable and resilient economic system.

Moreover, inflation is measured by the inflation rate, which represents the general and sustained increase in the prices of goods and services within an economy over a specific period. According to

Friedman (1970), inflation is primarily a monetary phenomenon that occurs when the growth of the money supply exceeds the growth of economic output. This relationship highlights the importance of effective monetary policy in maintaining price stability. In addition, Blanchard and Sheen (2013) explain that inflation can affect the economy in several ways, including reducing consumers' purchasing power and creating uncertainty for investors, although moderate levels of inflation may stimulate consumption and investment. The unemployment rate is also included as an important macroeconomic indicator and is defined as the percentage of the labor force that is unemployed but actively seeking work. According to the Organisation for Economic Co-operation and Development, the labor force includes both employed individuals and those unemployed individuals who are actively searching for employment. The unemployment rate is calculated as the number of unemployed persons divided by the total labor force, multiplied by 100.

Finally, regulatory quality is measured using the Regulatory Quality (RQ) index, which ranges from -2.5 (weak regulatory performance) to 2.5 (strong regulatory performance). This index evaluates the ability of governments to design and implement sound policies and regulations that enable and promote private sector development. High regulatory quality reflects effective, transparent, and predictable regulatory frameworks that facilitate investment, reduce corruption, and strengthen investor protection. Conversely, low regulatory quality may hinder economic development by increasing uncertainty and limiting the efficiency of markets. Therefore, the RQ index represents a crucial institutional indicator that helps policymakers and investors better understand the regulatory and business environment of a country.

Table 1: Summary of study variables

| Variable Name | Notation | Variable Measurement |
|---------------------|-----------|--|
| Economic growth | EG | The rate of change in real GDP. |
| CO2 Emission | CO2 | Measured as emissions per unit of GDP |
| Greenhouse Emission | GHGE | Measured as GHG emissions per unit of GDP |
| Globalization | GLOB | Globalization index (0-100) |
| Investment | INV | Capital investment as a percentage of GDP |
| Inflation | Inflation | The percentage change in the consumer price index |
| Unemployment | UNMP | The percentage of the working population in relation to the total population |
| Regulatory quality | RQ | Regulatory quality index (-2.5 weak; 2.5 strong) |

Note: The table presents the definition of the different variables used in this study

The variables presented in Table 1 summarize the key indicators used in this study to examine the relationship between economic growth, environmental performance, and macroeconomic conditions. Economic growth is captured by gross domestic product (GDP), which reflects the overall economic performance of a country. Environmental performance is represented by CO₂ emissions and greenhouse gas (GHG) emissions, both measured relative to GDP in order to account for energy efficiency and the environmental intensity of economic activity. In addition, the KOF Globalization Index is used to measure the level of global integration across economic, social, and political dimensions. Macroeconomic control variables include investment, inflation, and the unemployment rate, which capture key aspects of economic activity, price stability, and labor market conditions. Finally, regulatory quality is included as an institutional variable to reflect the effectiveness of government policies and the regulatory environment that may influence economic performance and

sustainable development. Together, these variables provide a comprehensive framework for analyzing the interactions between economic growth, environmental sustainability, globalization, and macroeconomic stability.

4. Result and Discussion

4.1. The Cross-dependence Test

Table 2: Cross-Sectional Dependence Test Results

| Test Statistic | Value |
|-----------------------|-----------|
| Chi-square (18) | 343.5500 |
| Probability (p-value) | 0.0000*** |

Note: This table reports the results of the cross-sectional dependence test. The null hypothesis assumes the absence of cross-sectional dependence among the panel units. The Chi-square statistic is used to test whether residuals across cross-sections are correlated. The results indicate that the null hypothesis of cross-sectional independence is rejected at the 1% significance level, suggesting the presence of cross-sectional dependence in the panel data.

The result of the dependence test, presented in Table 2, shows a probability less than 5%, which allows us to say that there is a significant correlation between the unit errors. This means that there is a significant cross-dependence between the unit errors. A detected cross-dependence suggests that the observations are not independent, which can bias the model estimates if not considered. This underlines the importance of using suitable models, such as fixed effects or random effects models, which can correct for this dependence. Indeed, a positive cross-dependence test indicates that it is necessary to adjust the models to ensure reliable and valid results.

4.2. Descriptive Statistics

Descriptive statistics provide a concise summary of the characteristics of a data set, allowing you to quickly identify trends and variations. They include measures such as the mean, median, and standard deviation, which help you better understand the distribution of values.

Table 3: Descriptive statistics

| Variable | Mean | Std. dev. | Min | Max |
|----------------------------|---------|-----------|----------|----------|
| Economic growth | 2.9082 | 3.5912 | -10.8900 | 14.2500 |
| CO2 emission | 8.1812 | 5.1401 | 0.8800 | 20.4700 |
| Greenhouse emission | 13.7274 | 0.9026 | 12.4729 | 16.3760 |
| Globalization | 72.7416 | 9.9957 | 46.1600 | 89.9700 |
| Investment | 24.4955 | 6.8575 | 9.9700 | 47.0300 |
| Inflation | 6.0914 | 14.5001 | -2.0000 | 211.4100 |
| Unemployment | 7.8663 | 5.5052 | 2.2000 | 34.300 |
| Regulatory quality | 0.5877 | 0.8207 | -1.1400 | 1.9400 |

Note: The table presents the descriptive statistics of the different variables used in this study

The descriptive statistics table reveals essential information on the economic and environmental variables of the G20 countries. First, economic growth has a mean of 2.9082, accompanied by a

standard deviation of 3.5912, indicating marked variation among countries. Indeed, the minimum and maximum values, ranging from -10.8900 to 14.2500, illustrate that some countries experienced periods of contraction, while others experienced strong expansion. Meanwhile, CO2 emissions have a mean of 8.1812 and a standard deviation of 5.1401, suggesting significant differences in environmental policies and industrial intensity. Values ranging from 0.8800 to 20.4700 highlight the urgency of adopting sustainable development strategies, particularly for large emitters. Regarding greenhouse gas emissions, the mean of 13.7274 and the low standard deviation of 0.9026 reveal greater homogeneity, with the minimum and maximum values being 12.47 and 16.3760, respectively. This means that, although emissions are high, variations between countries are less marked. For globalization, with a mean of 72.7416 and a standard deviation of 9.9957, the G20 countries display a fairly high level of economic integration, although scores range from 46.1600 to 89.9700, which can be attributed to distinct national policies.

Regarding investment, the mean of 24.4955 and the standard deviation of 6.8575 indicate disparities, with levels ranging from 9.9700 to 47.0300, reflecting diverse economic contexts. Furthermore, inflation, with an average of 6.0914 and a high standard deviation of 14.5001, shows great volatility, with some countries posting very low rates while others reach alarming inflation levels, up to 211.4100.

The unemployment rate, which stands at an average of 7.8663 and a standard deviation of 5.5052, also shows significant divergences, ranging from 2.2000 to 34.3000, which can have serious repercussions on social and economic stability. Finally, regulatory quality, with an average of 0.5877 and a standard deviation of 0.8207, indicates that G20 countries exhibit varying levels of governance, ranging from -1.1400 to 1.9400. This can influence their ability to attract investment and maintain a stable economic environment.

4.3 Correlation Matrix

The correlation matrix is a statistical tool that shows the relationships between multiple variables by indicating the strength and direction of their associations. Each element of the matrix represents the correlation coefficient between two variables, ranging from -1 to 1, where values close to 1 indicate a strong positive correlation, values close to -1 a strong negative correlation, and values around 0 an absence of correlation.

Table 4 : Correlation Matrix

| Variable | CO2 emission | Greenhouse emission | Globalization | Investment | Inflation | Unemployment | Regulatory quality |
|----------------------------|--------------|---------------------|---------------|------------|------------|--------------|--------------------|
| CO2 emission | 1.0000 | | | | | | |
| Greenhouse emission | 0.1542* | 1.0000 | | | | | |
| Globalization | 0.0822 | -0.2305** | 1.0000 | | | | |
| Investment | 0.1672* | 0.3036*** | 0.2186** | 1.0000 | | | |
| Inflation | -0.3040*** | -0.1583* | -0.0810 | -0.1906* | 1.0000 | | |
| Unemployment | -0.2379** | -0.2852*** | 0.1112 | -0.4614*** | 0.2018* | 1.0000 | |
| Regulatory quality | 0.5195*** | -0.0996 | 0.3167*** | -0.0106 | -0.4778*** | -0.2090* | 1.0000 |

Note: ***, **, *: denote the significance level at the threshold of 1%, 5%, and 10%, respectively.

The correlation matrix in Table 4 highlights the relationships between several economic and environmental variables in the G20 countries. First, it is crucial to note that none of the observed correlations exceed 0.6, indicating that there is no autocorrelation problem in these data. Indeed, correlation values above 0.6 could suggest a strong dependence between variables, but here, the values remain moderate, which is consistent with the observations of several authors on the dynamics of economic and environmental relationships. Furthermore, CO2 emissions show a moderate positive correlation with both greenhouse gas emissions (0.1542) and investment (0.1672). This could indicate that higher levels of investment are associated with higher CO2 emissions, which is often the case in developing economies where economic growth is accompanied by increased emissions, as Smith et al. (2022) pointed out. In contrast, CO2 emissions show a negative correlation with inflation (-0.3040) and unemployment (-0.2379), suggesting that higher inflation and higher unemployment could be linked to lower CO2 emissions, which could be interpreted as a reduction in economic activity.

Furthermore, globalization shows a weak positive correlation with investment (0.2186) and a negative correlation with greenhouse gas emissions (-0.2305). This indicates that more globalized countries tend to have higher investments while adopting more sustainable practices, which reduces their greenhouse gas emissions, as noted by Adzawla et al. (2019). Furthermore, regulatory quality is positively correlated with globalization (0.3167) and CO2 emissions (0.5195), suggesting that stricter regulations can encourage more sustainable business practices and better resource management. Finally, it is worth mentioning that inflation and unemployment show negative correlations with regulatory quality (-0.4778 and -0.2090, respectively), indicating that higher quality regulations are associated with lower levels of inflation and unemployment. This reinforces the idea that governance plays a crucial role in economic performance, as highlighted by Davis (2021).

4.4 Multicollinearity Test

The multicollinearity test is crucial to ensure that regression coefficients are accurate and meaningful, as high multicollinearity can lead to unstable estimates. By identifying correlated variables, this test also helps simplify the model, making the analysis clearer and predictions more robust.

Table 5: VIF test

| Variables | VIF | 1/VIF |
|---------------------------|--------|--------|
| Regulatory quality | 2.1900 | 0.4565 |
| INV | 1.7100 | 0.5832 |
| Unemployment | 1.5600 | 0.6395 |
| CO2 | 1.5000 | 0.6665 |
| Globalization | 1.4700 | 0.6813 |
| Inflation | 1.4300 | 0.7008 |
| GHGE | 1.3000 | 0.7686 |
| Mean VIF | 1.5900 | |

Note: VIF refers to the Variance Inflation Factor, which measures the degree of multicollinearity among the explanatory variables in a regression model. A VIF value exceeding 10 is commonly considered indicative of severe multicollinearity, while values above 5 may signal moderate multicollinearity. In this study, all VIF values are well below these thresholds, suggesting that multicollinearity is not a concern and that the estimated coefficients are reliable.

The variance inflation factor (VIF) presented in Table 5 provides values that enable us to assess the presence of multicollinearity among the model variables. Generally, a VIF greater than 5 is considered a concerning indicator of multicollinearity, while a VIF exceeding 10 suggests severe multicollinearity. In this case, the VIF values for the various variables are all less than 3, indicating that multicollinearity is not a significant issue in this model.

The regulatory quality variable exhibits the highest VIF at 2.1900, followed by investment (1.7100) and unemployment (1.5600). These values indicate that, while there is some correlation among these variables, they are not sufficiently collinear to compromise the estimation of the regression coefficients. Other variables, such as CO2 emissions (1.5000), globalization (1.47000), inflation (1.4300), and greenhouse gas emissions (1.3000), also have relatively low VIFs. Furthermore, the average VIF is 1.5900, reinforcing the notion that there is no significant multicollinearity present in the model. Consequently, the results suggest that the coefficients of the variables can be interpreted reliably, as multicollinearity does not appear to affect the stability of the estimates.

4.5. Discussion of Results

4.5.1 Stationarity Test

Before estimating the empirical models, several diagnostic tests were conducted to ensure the reliability and validity of the panel regression results. One of the most critical preliminary steps in panel data analysis is testing the stationarity properties of the variables. Stationarity ensures that the statistical properties of the series, such as mean and variance, remain constant over time, thereby preventing misleading regression results.

Table 6: Stationarity test

| Variable | LLC statistic | p-value | IPS statistic | p-value | ADF-Fisher statistic | p-value | Order |
|---------------------------|---------------|---------|---------------|---------|----------------------|---------|-------|
| Economic growth | -3.8700* | 0.0000 | -2.9400* | 0.0020 | 68.2100* | 0.0000 | I(0) |
| CO ₂ emissions | -2.6100* | 0.0040 | -2.0800 | 0.0190 | 57.4600 | 0.0060 | I(0) |
| Greenhouse emissions | -2.4800 | 0.0070 | -1.9900 | 0.0230 | 55.1200 | 0.0090 | I(0) |
| Globalization | -2.7200* | 0.0030 | -2.1500 | 0.0160 | 59.3400 | 0.0050 | I(0) |
| Investment | -2.4100 | 0.0080 | -1.9700 | 0.0240 | 55.6300 | 0.0090 | I(0) |
| Inflation | -4.1200* | 0.0000 | -3.3600* | 0.0010 | 72.4500* | 0.0000 | I(0) |
| Unemployment | -2.2900 | 0.0110 | -1.8800 | 0.0310 | 53.7800 | 0.0120 | I(0) |
| Regulatory quality | -2.7600* | 0.0030 | -2.2100 | 0.0140 | 60.3400 | 0.0040 | I(0) |

Note: ***, **, *: denote the significance level at the threshold of 1%, 5%, and 10%, respectively.

Table 6 presents the results of panel unit root tests conducted using standard procedures, including the Levin–Lin–Chu (LLC) test, Im–Pesaran–Shin (IPS) test, and Fisher-type Augmented Dickey–Fuller (ADF) and Phillips–Perron (PP) tests. The initial results suggest that all variables, namely Economic Growth (EG), Carbon Dioxide Emissions (CO₂), Greenhouse Gas Emissions (GHGE), and the Globalization Index (GLOB), appear to be stationary at a level, indicating an integration order of I(0).

However, this outcome requires careful interpretation. In macroeconomic and environmental datasets, variables such as CO₂ emissions and globalization indices are typically characterized by persistent

trends and structural dynamics, which often result in non-stationary behavior. Therefore, the stationarity findings obtained in this study were rigorously re-examined using additional robustness checks, including alternative unit root testing specifications and cross-sectional dependence adjustments. These additional analyses were conducted to minimize the risk of model misspecification and ensure the robustness of the stationarity conclusions.

Despite the statistical indication of stationarity, the possibility of spurious regression cannot be entirely excluded. The literature highlights that even when variables appear stationary, regression relationships may still be misleading under certain conditions, particularly when the variables exhibit near non-stationary characteristics or strong persistence. Cheng et al. (2021) demonstrate that nearly non-stationary time series can generate false statistical relationships that appear significant despite lacking genuine economic meaning. Their findings emphasize the importance of carefully evaluating the time-series properties of macroeconomic variables, especially in panel frameworks.

Similarly, Wong et al. (2024) argue that regressions involving stationary series may still produce spurious results when underlying structural dependencies or hidden persistence patterns exist. Their research suggests that stationarity alone does not guarantee the validity of econometric relationships, particularly when data are influenced by long-term equilibrium adjustments or omitted dynamic components.

Furthermore, Wong and Yue (2024) highlight that regressions combining stationary and non-stationary variables may generate statistically significant but economically meaningless results. Their study underscores the necessity of ensuring consistency in the integration order of variables and conducting additional robustness tests to confirm the reliability of empirical findings.

4.5.2 Normality Test of Residuals

To verify the assumption of normality of the residuals of the estimated panel model, the Jarque–Bera (JB) test was applied to the overall residuals. The results are presented in Table 7.

Table 7: Normality Test of Model Residuals

| Statistic | Value |
|-------------|---------|
| Jarque–Bera | 1.8700 |
| Probability | 0.3920 |
| Skewness | -0.1400 |
| Kurtosis | 2.9600 |

Note: The null hypothesis of the Jarque–Bera test is that residuals are normally distributed.

The results in Table 7 indicate that the Jarque–Bera statistic test does not reject the null hypothesis of normality of the residuals (p-value > 0.05), indicating that the errors follow an approximately normal distribution. This property strengthens the validity of the statistical tests associated with the estimated coefficients.

4.5.3 Autocorrelation Test: Durbin–Watson Statistic

The presence of autocorrelation of errors was tested using the Durbin–Watson (DW) statistic. The results are reported in Table 8.

Table 8: Durbin–Watson Test for Autocorrelation

| Model | Durbin–Watson statistic |
|----------------------|-------------------------|
| Baseline panel model | 1.9800 |

Note: A Durbin–Watson statistic close to 2 indicates no first-order autocorrelation.

As shown in Table 8, the Durbin–Watson statistic close to the theoretical value of 2, suggests the absence of first-order autocorrelation of the residuals. This implies that the estimates are not subject to biases related to an unaccounted-for serial dependence.

4.5.4 Nonlinearity Test

To verify the validity of the linear specification of the model, a nonlinearity test inspired by Hui et al. (2017) was applied. This test examines the possible existence of nonlinear relationships not captured by the chosen linear functional form. The results are presented in Table 9.

Table 9: Nonlinearity Test Results

| | Statistic | p-value |
|-------------------------------------|-----------|---------|
| Hui et al. (2017) nonlinearity test | 1.3400 | 0.1820 |

Note: The null hypothesis assumes linearity of the estimated model.

Table 9 shows that the nonlinearity test does not reveal any significant deviation from the linear form of the model. The hypothesis of linearity cannot, therefore, be rejected, which confirms the suitability of the adopted econometric framework.

4.5.5 Discussion of Regression Results

The importance of the relationship between CO₂ emissions, greenhouse gases (GHGs), and economic growth is particularly evident in the context of the G20 countries, which account for a significant share of global emissions.

Table 10: The impact of CO₂ and Greenhouse Gas Emission on Economic Growth: The direct effect step one of the Baron and Kenney process

| EG | Model 1 | | | Model 2 | | | Model 3 | | |
|--------------------|-------------|---------|-----------|-------------|---------|-----------|-------------|---------|-----------|
| | Coefficient | t | P> t | Coefficient | t | P> t | Coefficient | t | P> t |
| CO ₂ | 2.1680 | 5.3300 | 0.0000*** | | | | | | |
| GHGE | | | | 12.1037 | 3.1400 | 0.0020*** | | | |
| Globalization | | | | | | | 4.7803 | 2.2800 | 0.0250** |
| Inv | 0.3973 | 2.1400 | 0.0340** | 0.4881 | 2.4800 | 0.0150** | 0.9568 | 4.0800 | 0.0000*** |
| Inflation | -0.1264 | -2.5100 | 0.0130** | -0.1472 | -2.7000 | 0.0080*** | 0.0544 | 0.9800 | 0.3270 |
| Unemployment | -0.1463 | -0.7400 | 0.4630 | -0.1541 | -0.7100 | 0.4800 | -0.0874 | -0.3200 | 0.7510 |
| Regulatory quality | 4.7572 | 2.4500 | 0.0160** | 3.1476 | 1.5500 | 0.1240 | -2.5430 | -1.0600 | 0.2920 |
| R ² | 0.4492 | | | 0.3749 | | | 0.2837 | | |
| Fisher | 10.4400 | | | 7.6800 | | | 3.6900 | | |

| | | | |
|----------------|-----------------------|------------------------|-----------------------|
| | 0.0000 | 0.0000 | 0.0001 |
| Hausman | 59.6700 "p<0.0001" | 163.9300 "p<0.0001" | 27.2800 "p<0.0001" |

Notes: This table reports panel data estimations of the impact of environmental, macroeconomic, and institutional factors on economic performance, based on Equations (1), (2), and (3). EG denotes economic growth. CO2 represents carbon dioxide emissions, while GHGE refers to greenhouse gas emissions. GLOB is the globalization index, INV denotes the investment rate, Inflation is the inflation rate, UNMP represents the unemployment rate, and RQ measures regulatory quality. t-statistics and corresponding p-values are reported in parentheses. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

Table 10 presents the results of the direct effects analysis based on the Baron and Kenny (1986) methodology, highlighting the relationships between CO2 emissions, greenhouse gas emissions (GHGE), and economic growth (EG) within the context of the G20 countries. In the first model, CO2 emissions exhibit a coefficient of 2.1680 ($t = 5.3300$, $p < 0.000$), indicating a positive and significant relationship with economic growth. This finding suggests that an increase in CO2 emissions is associated with enhanced economic growth, a trend often observed in developing economies that depend on polluting energy sources, as noted by Zhang et al. (2020). Additionally, investment shows a coefficient of 0.3973 ($p = 0.0340$), confirming that higher levels of investment foster growth, a conclusion supported by recent research (Sabado et al., 2023). Regulatory quality, with a coefficient of 4.7572 ($p = 0.0160$), also indicates that improved regulations can stimulate growth; however, this may sometimes lead to unsustainable practices, as highlighted by Cheng et al. (2021). The R^2 value of 0.4492 signifies that 44.92% of the variance in economic growth is explained by the model's variables, demonstrating its strong explanatory power. The Fisher test (10.4400, $p < 0.0000$) confirms the model's significance, while the Hausman test (59.6700, $p < 0.0000$) validates the appropriateness of using a fixed-effects model.

In the second model, GHGE emissions become the dependent variable. The results reveal a positive coefficient of 12.1037 ($t = 3.1400$, $p = 0.0020$), indicating that increased GHGE emissions are associated with economic growth. Investment remains significant with a coefficient of 0.4882 ($p = 0.0150$), reinforcing the notion that investments in polluting sectors contribute to the escalation of emissions. In contrast, regulatory quality does not demonstrate a significant effect on GHGE (3.1477, $p = 0.1240$), suggesting that existing policies may be insufficient to reduce emissions. The R^2 value of 0.3749 indicates that 37.49% of the variance is explained, which is a decrease compared to the first model. The Fisher test (7.6800, $p < 0.0001$) confirms the significance of the model, while the Hausman test (163.9300, $p < 0.0000$) supports the use of a fixed-effects model.

Finally, in the third model, globalization is introduced. The coefficient of 4.7803 ($t = 2.2800$, $p = 0.0250$) for globalization indicates that greater economic integration is associated with increased economic growth, which can open new markets, but may also lead to higher emissions, as indicated by several studies (Davis, 2021). Investment in this model is particularly robust with a coefficient of 0.9568 ($p < 0.000$), underscoring its critical role in driving economic growth. However, inflation exhibits a negative coefficient that lacks significance (0.0544, $p = 0.3270$), and the variables related to unemployment and regulatory quality do not demonstrate significant effects. The R^2 value of 0.2837 indicates that only 28.37% of the variance is explained, which is relatively low. Fisher's test ($F=3.6900$, $p < 0.0000$) reveals that the model is statistically significant, while the Hausman test ($\chi^2 = 27.2800$, $p = 0.0114$) suggests caution in the use of random effects.

Table 11: The impact of CO2 and Greenhouse Gas Emissions on Globalization: The direct effect according to the Baron and Kenney process

| Globalization | Model 4 | | | Model 5 | | |
|--------------------|-----------------------|---------|-----------|-----------------------|---------|-----------|
| | Coefficient | z | P> z | Coefficient | t | P> t |
| CO2 | -0.9385 | -4.6000 | 0.0000*** | | | |
| GHGE | | | | -18.9679 | -4.4000 | 0.0000*** |
| Inv | 0.2672 | 1.9800 | 0.0480** | -0.1502 | -0.7300 | 0.4660 |
| Inflation | -0.0432 | -0.7400 | 0.4570 | -0.0342 | -0.6100 | 0.5410 |
| Unemployment | 0.3552 | 2.3800 | 0.0180** | 0.2990 | 1.2100 | 0.2300 |
| Regulatory quality | -2.8887 | -1.3000 | 0.1920 | -2.7945 | -1.2400 | 0.2160 |
| R2 | 0.5879 | | | 0.2511 | | |
| Fisher | 49.9800 0.0000*** | | | 3.6900 0.0003*** | | |
| Hausman | 17.4300 "p<0.0001" | | | 33.2800 "p<0.0001" | | |

Notes: This table reports panel data estimations of the impact of environmental, macroeconomic, and institutional factors on economic performance, based on Equations (4) and (5). GLOB is the globalization index, CO2 represents carbon dioxide emissions, while GHGE refers to greenhouse gas emissions. INV denotes the investment rate, Inflation is the inflation rate, UNMP represents the unemployment rate, and RQ measures regulatory quality. z-statistics (model 4), t-statistics (model 5) and corresponding p-values are reported in parentheses. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

In the fourth model, the results indicate that CO2 emissions have a coefficient of -0.9386 ($z = -4.6000$, $p < 0.000$), demonstrating a negative and significant relationship with globalization. This suggests that an increase in CO2 emissions is associated with a decrease in globalization, which can be interpreted as a consequence of international pressures to reduce emission levels. This observation is supported by the research of Smith et al. (2022), who emphasize that countries with high emission levels may encounter barriers to their global economic integration due to stringent environmental regulations. Furthermore, investment has a positive coefficient of 0.2672 ($t = 1.9800$, $p = 0.0480$), indicating that an increase in investment is linked to greater globalization. This finding is corroborated by recent studies, such as that by Sabado et al. (2023), which demonstrate that foreign direct investment fosters economic integration. In contrast, inflation exhibits a coefficient of -0.0433 ($t = -0.7400$, $p = 0.4570$), which is not statistically significant. This suggests that there is no direct relationship between inflation and globalization. For unemployment, the positive coefficient of 0.3553 ($t = 2.3800$, $p = 0.0180$) indicates that an increase in unemployment is associated with an increase in globalization. This may reflect a dynamic in which countries with high unemployment rates seek greater integration to stimulate their economies, as noted by Lee et al. (2024). Finally, regulatory quality shows a negative coefficient of -2.8888 ($t = -1.3000$, $p = 0.1920$), indicating that there is no significant direct relationship between regulatory quality and globalization. The R^2 value of 0.5879 indicates that 58.79% of the variance in globalization is explained by the model's variables, demonstrating good explanatory power. The Fisher test result (49.9800, $p < 0.0000$) confirms the model's significance, while the Hausman test (17.4300, $p = 0.0654$) suggests that it may be prudent to use fixed effects.

In the fifth model, the results indicate that greenhouse gas emissions (GHGE) have a coefficient of -18.9680 ($t = -4.4000$, $p < 0.000$), demonstrating a negative and significant relationship with globalization. This finding reinforces the notion that high levels of GHGE are also associated with reduced globalization, potentially due to the environmental commitments of G20 countries that restrict

their trade. Regarding investment, the coefficient is -0.1502 ($t = -0.7300$, $p = 0.4660$), indicating that there is no significant relationship between investment and globalization in this model. This may suggest that the effects of investment on globalization are more complex and could be influenced by other factors. Inflation continues to exhibit a negative coefficient of -0.0342 ($t = -0.6100$, $p = 0.5410$), which is not statistically significant, confirming that there is no direct link between inflation and globalization. For unemployment, the coefficient is 0.2990 ($t = 1.2100$, $p = 0.2300$), indicating that unemployment does not have a significant effect on globalization in this model. Finally, regulatory quality has a negative coefficient of -2.7945 ($t = -1.2400$, $p = 0.2160$), highlighting the absence of a significant relationship with globalization. The R^2 value of 0.2511 indicates that 25.11% of the variance in globalization is explained by the model's variables, which is lower than in the first model. The Fisher test (3.6900, $p < 0.0003$) confirms the overall significance of the model, while the Hausman test (33.2800, $p < 0.0002$) suggests that fixed effects may be more appropriate in this context.

Table 12: The mediating role of globalization on the relationship among CO2, greenhouse emissions, and economic growth

| | Model 6 | | | Model 7 | | |
|--|----------------------|---------|-----------|-----------------------|---------|-----------|
| | Coefficient | z | P> z | Coefficient | z | P> z |
| CO2 | 0.0566 | 0.6400 | 0.5250 | | | |
| GHGE | | | | -0.8132 | -1.3000 | 0.1920 |
| Globalization | 4.3801 | 1.9700 | 0.0490** | 4.3704 | 1.9700 | 0.0480** |
| Inv | 0.3783 | 5.4300 | 0.0000*** | 0.4424 | 6.2500 | 0.0000*** |
| Inflation | -0.0233 | -0.5700 | 0.5670 | -0.02789 | -0.6900 | 0.4900 |
| Unemployment | 0.0546 | 0.9300 | 0.3520 | 0.0684 | 1.2200 | 0.2220 |
| Regulatory quality | 1.2289 | 1.0500 | 0.2960 | 0.5261 | 0.4100 | 0.6850 |
| R2 | 0.8162 | | | 0.8132 | | |
| Fisher | 69.4700 0.0000 | | | 71.5000 0.0000 | | |
| Hausman | 6.4200 "p<0.0001" | | | 16.9800 "p<0.0001" | | |
| Notes: This table reports panel data estimations of the impact of environmental, macroeconomic, and institutional factors on economic performance, based on Equations (6) and (7). EG denotes economic growth. CO2 represents carbon dioxide emissions, while GHGE refers to greenhouse gas emissions. GLOB is the globalization index, INV denotes the investment rate, Inflation is the inflation rate, UNMP represents the unemployment rate, and RQ measures regulatory quality. z-statistics and corresponding p-values are reported in parentheses. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively. | | | | | | |

Table 12 examines the mediating effect of globalization on the relationship among CO2 emissions, greenhouse gas emissions (GHGE), and economic growth (EG) (Models 6 and 7). We observe interesting results that align with Baron and Kenny's (1986) methodology. In the first model, CO2 emissions exhibit a coefficient of 0.05670 ($z = 0.6400$, $p = 0.5250$), indicating that there is no significant relationship between CO2 emissions and economic growth. This finding suggests that, contrary to some hypotheses, CO2 emissions do not directly stimulate economic growth, a conclusion supported by recent studies (Zhang et al., 2020). Although greenhouse gas emissions (GHGE) are not directly included in this model, it is noteworthy that they present a coefficient of -0.8132 ($z = -1.3000$, $p = 0.1920$) regarding their impact on economic growth. Although this coefficient is not statistically significant, it underscores a negative trend that could be intensified by stringent environmental policies in G20 countries, thereby restricting growth opportunities for polluting industries.

Globalization in this model is significantly associated with economic growth, exhibiting a coefficient of 4.3801 ($z = 1.9700$, $p = 0.0490$). This suggests that greater economic integration fosters growth. This finding is supported by recent research, including the work of Sabado et al. (2023), which demonstrates that globalization enables countries to access new markets and enhance their competitiveness. Consequently, globalization emerges as a crucial factor that can alleviate the adverse effects of emissions on economic growth.

The analysis of the results underscores the critical role of globalization as a mediator between CO₂ emissions, greenhouse gas emissions (GHGE), and economic growth. In the sixth model, although CO₂ emissions do not exhibit a significant relationship with economic growth (coefficient of 0.0567, $z = 0.6400$, $p = 0.5250$), the presence of globalization as a mediating variable is vital. Indeed, globalization has a coefficient of 4.3801 ($z = 1.9700$, $p = 0.0490$), indicating that it fosters economic growth. This suggests that even if CO₂ emissions do not have a direct impact, their influence can be mitigated through increased economic integration, allowing countries to benefit from access to new markets and enhance their competitiveness. In the seventh model, globalization remains significant (coefficient of 4.3705, $z = 1.9700$, $p = 0.0480$), reaffirming its mediating role between GHGE emissions and economic growth. Although GHGE emissions display a negative trend (coefficient of -0.8132, $z = -1.3000$, $p = 0.1920$), globalization helps offset these effects by promoting policies that support innovation and access to cleaner technologies. This is particularly relevant in the context of G20 countries, where the pressure to reduce emissions is accompanied by the need to ensure economic growth.

Certainly, based on the results, we can conclude that globalization serves not only as a catalyst for growth but also as a mechanism to mitigate the potentially negative effects of CO₂ and GHGE emissions on the economy. This underscores the importance of a sustainable development strategy that integrates both environmental and economic dimensions, thereby enabling inclusive growth while addressing global environmental challenges. The findings of this analysis are corroborated by recent studies indicating that economically integrated countries are more likely to adopt more sustainable practices, thereby fostering a synergy between growth and sustainability (Sabado et al., 2023).

The panel regression results reveal that environmental degradation indicators, particularly CO₂ and GHGE emissions, exert significant effects on economic growth across G20 countries. The estimated coefficients suggest that higher emission levels are generally associated with adverse economic consequences, reflecting the increasing economic costs of environmental degradation and climate-related risks.

Globalization, however, exhibits a more complex and nuanced impact. The results indicate that globalization positively influences economic growth by facilitating trade expansion, capital mobility, and technology transfer. At the same time, globalization demonstrates a mediating role in the relationship between environmental degradation and economic growth. In several G20 countries, globalization appears to mitigate the negative economic effects of environmental pressures by promoting access to cleaner technologies and more efficient production processes.

These findings support the argument that globalization can function as both a driver of environmental challenges and a potential mechanism for sustainable development. The dual nature of globalization reflects differences in institutional quality, environmental regulations, and technological capacities across countries.

The empirical findings provide important insights for policymakers and strategic decision-makers. The results suggest that globalization strategies must be accompanied by strong environmental governance frameworks to prevent the relocation of polluting industries and ensure sustainable economic growth. Countries that successfully integrate globalization with environmental innovation and regulatory enforcement appear better positioned to achieve balanced development outcomes.

From a Decision Sciences perspective, the results highlight the importance of incorporating environmental risks and globalization dynamics into strategic economic planning. Policymakers must evaluate trade-offs between economic expansion and environmental sustainability while accounting for global interdependencies and technological transformation processes.

Indeed, the R^2 value of the first model is 0.8162, indicating that 81.62% of the variance in economic growth is explained by the independent variables, which demonstrates very good explanatory power. The Fisher test (69.4700, $p < 0.0000$) confirms that the model is globally significant, while the Hausman test (6.4200, $p = 0.0864$) suggests the possibility of random effects, although this finding should be approached with caution. Similarly, the R^2 of the second model is 0.8132, also indicating a good explanatory power, albeit slightly lower than that of the first model. The Fisher test (71.5000, $p < 0.0000$) confirms its significance, while the Hausman test (16.9800, $p = 0.0725$) suggests that fixed effects may be more appropriate in this context. These results clearly validate the mediating role of globalization between CO₂ emissions, greenhouse gas emissions, and economic growth.

5. Conclusion

Restatement of Motivation and Research Problem

Understanding how globalization shapes the relationship between environmental degradation and economic performance has become a critical issue in the current global context, particularly for G20 countries, which account for a substantial share of global economic activity and greenhouse gas emissions. Increasing environmental pressures, combined with the growing intensity of international economic integration, have raised fundamental questions regarding the sustainability of growth models. This study was motivated by the need to determine whether globalization merely coexists with environmental degradation or actively mediates its impact on economic growth. By focusing on the period 2010–2024, this research contributes to ongoing policy and academic debates concerning sustainable development, climate commitments, and the economic consequences of globalization.

Summary of Main Findings

The empirical results provide evidence that carbon dioxide emissions and greenhouse gas emissions do not exert a statistically significant direct effect on economic growth once globalization is incorporated into the econometric framework. Instead, globalization emerges as a central mediating

factor that promotes economic growth even in contexts characterized by relatively high emission levels. The findings suggest that globalization facilitates economic performance through mechanisms such as technological diffusion, international knowledge spillovers, and increased access to advanced production methods. These mechanisms appear to partially offset the negative growth effects typically associated with environmental degradation. Overall, the results highlight the complex and multidimensional nature of the globalization–environment–growth nexus across G20 economies.

Importance for Academics and Practitioners

The results offer significant implications for both academic research and practical policymaking. For academics, the study contributes to a deeper understanding of the interactions between environmental and economic dynamics by emphasizing the role of globalization as a transmission channel rather than a simple explanatory factor. For policymakers and practitioners, the findings highlight the importance of adopting integrated development strategies that simultaneously address environmental sustainability and economic integration. The study suggests that international cooperation, technology transfer policies, and environmentally oriented innovation strategies can help countries achieve sustainable growth while maintaining competitiveness in the global economy.

Originality and Contributions of the Study

This study contributes to the literature in several important ways. Theoretically, it advances existing research by conceptualizing globalization as a mediating mechanism linking environmental emissions to economic growth, thereby providing a more comprehensive analytical perspective on the growth–environment relationship. Empirically, the study offers updated and comparative evidence based on a balanced panel of G20 countries over a recent and extended period, strengthening the robustness and relevance of the findings. Methodologically, the integration of mediation analysis within a panel econometric framework provides a more nuanced understanding of the complex interactions between globalization, environmental degradation, and economic performance, extending prior studies that predominantly focused on direct causal relationships.

Limitations and Directions for Future Research

Despite its contributions, this study has several limitations. First, the analysis focuses exclusively on G20 countries, which may limit the generalizability of the results to developing and low-income economies where structural conditions and globalization dynamics may differ significantly. Second, although the study period captures recent economic and environmental developments, it may not fully reflect the long-term dynamic effects of globalization and environmental policies. Future research could extend the analysis by incorporating emerging and developing economies, applying nonlinear and dynamic modeling approaches, or integrating additional mediating and moderating variables such as institutional quality, technological innovation, and renewable energy adoption. Such extensions would provide deeper insights into the evolving interactions between globalization, environmental sustainability, and economic development.

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