

# The role of green finance and innovation in advancing environmental sustainability in South America

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## Abstract

**Purpose** – This study examines the impact of green finance (GFIN) and green innovation (GTI) on environmental sustainability in seven South American countries from 2000 to 2020.

**Design/methodology/approach** – The study employs panel data econometric techniques using the Method of Moments Quantile Regression approach to explore the relationships between carbon dioxide (CO<sub>2</sub>) emissions, GFIN, GTI, economic growth (GDP), renewable energy (REN) and non-renewable energy (NRE) globalization (GLO) and population (POP). The robustness of the results is confirmed through additional analyses using bootstrap quantile regression, feasible generalized least squares and panel corrected standard errors.

**Findings** – The findings reveal that GFIN significantly reduces CO<sub>2</sub> emissions across all quantiles, with stronger effects at higher quantiles. However, GTI shows a positive association with emissions in higher quantiles, suggesting rebound effects. Renewable energy decreases emissions, while NRE, GLO, population and GDP growth contribute to environmental degradation, indicating no evidence of the environmental Kuznets curve hypothesis. Additionally, the Dumitrescu-Hurlin causality test reveals bidirectional causality between carbon dioxide (CO<sub>2</sub>), GDP, NRE and POP, and unidirectional causality from CO<sub>2</sub> to GFIN, GTI and REN, highlighting dynamic interactions.

**Practical implications** – The results suggest that policymakers should promote accessible GFIN, enhance the efficiency of green innovation and invest in REN sources to support environmental sustainability.

**Originality/value** – This study offers novel insights by applying a quantile-specific approach to examine the impacts of GFIN and innovation on environmental sustainability in South America, addressing a significant gap in the literature where such distributional effects in emerging economies have been largely overlooked.

**Keywords** Green finance, Green innovation, Carbon emissions, Environmental sustainability, MMQR, EKC, South America

**Paper type** Research article



**JEL Classification** — C31, C54, O54, Q54, Q56, Q58

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## 1. Introduction

Achieving environmental sustainability has become one of the most pressing global challenges in the 21st century, especially for regions like South America, which experience unique environmental, social and economic dynamics (Hwang and Díez, 2024). South America's ecological richness is juxtaposed with mounting environmental pressures, including deforestation, urbanization and reliance on fossil fuels (Hwang, 2023). Despite global attention to sustainable development, the region's environmental policies often fall short in addressing the scale of these challenges (Koengkan and Fuinhas, 2022). In this context, the dual crises of climate change and ecological degradation necessitate innovative solutions and strategic financial mechanisms. This study aims to address these challenges by examining the role of green finance (GFIN) and innovation in mitigating environmental degradation, proxied by carbon dioxide (CO<sub>2</sub>) emissions, in seven South American countries from 2000 to 2020, using the Method of Moments Quantile Regression (MMQR) approach. GFIN represents investments that promote sustainable development while reducing environmental risks (Miyan *et al.*, 2024), and green innovation signifies technological and process advancements that reduce environmental impact (Rupasinghe *et al.*, 2024); both are increasingly recognized as pivotal tools for achieving sustainability (Feng, 2022; Gul and Hussain, 2024; Jian and Afshan, 2022; Sethi *et al.*, 2024; Sharif *et al.*, 2022). However, there is limited empirical evidence on how these mechanisms interact with key macroeconomic and demographic factors in South America, where diverse socio-economic contexts exist across countries. This gap highlights the urgency of investigating how GFIN and innovation contribute to reducing environmental degradation within this region.

While prior studies on environmental sustainability have primarily focused on developed or rapidly industrializing regions (Jian and Afshan, 2022; Sharif *et al.*, 2022), South America remains underexplored despite its critical role in global biodiversity and climate restoration. Although some studies have addressed South American or Latin American contexts, hardly any have centered on GFIN and green innovation within the Environmental Kuznets Curve (EKC) framework (Bickel and Mia, 2023; Fuinhas *et al.*, 2017, 2021; Hwang, 2023; Hwang and Díez, 2024; Koengkan and Fuinhas, 2022). Additionally, existing studies often rely on long-run mean-based regressions, leading this study to employ the MMQR approach, which is more robust to non-normal data, addresses panel data inconsistencies and accommodates mixed integration orders (Fu and Zhu, 2023; Koenker and Bassett Jr, 1978). Additionally, the EKC hypothesis, which posits an inverted U-shaped relationship between economic growth and environmental degradation, has been widely debated. Despite the appealing concept of the EKC, it is crucial to acknowledge that the empirical data substantiating the EKC are tenuous and decidedly unclear (Smulders *et al.*, 2014). However, its validity in South America, where economic development often coexists with persistent environmental degradation, remains underexplored. Furthermore, while GFIN and innovation have been studied individually, their combined impact, especially in the presence of other factors such as globalization (GLO), renewable and non-renewable energy (NRE) use and population dynamics, has not been adequately analyzed. Additionally, this study contributes to the existing literature by employing the MMQR econometric model initiated by Machado and Silva (2019), which captures the heterogeneous effects of explanatory variables across different quantiles of CO<sub>2</sub> emissions. Unlike conventional methods that focus on mean effects, MMQR provides a more nuanced understanding of how GFIN, innovation and other factors influence environmental degradation at varying levels. Furthermore, this research explicitly integrates CO<sub>2</sub> emissions as proxies for environmental sustainability, offering a more comprehensive assessment. By focusing on seven South American countries over two decades, this study provides comprehensive, methodologically robust and region-specific insights that are critical for tailoring policy interventions.

The selection of seven South American countries—Argentina, Brazil, Chile, Colombia, Ecuador, Peru and Uruguay—as the research context is highly appropriate, given the region's dual role as a global climate regulator and a zone grappling with persistent sustainability challenges. Meanwhile, national-level GFIN initiatives in Latin America provide valuable insights into the effectiveness of green financial instruments in emerging economies. For

instance, Colombia launched the first Green Taxonomy in Latin America in 2022, in collaboration with the Climate Bonds Initiative and UK Partnering for Accelerated Climate Transitions (PACT), to classify economic activities that genuinely contribute to environmental objectives, such as emission reduction and climate resilience (Climate Bonds Initiative, 2024). The region has also advanced in implementing supportive government protocols and regulatory frameworks that encourage the development of eco-friendly financial products, including biodiversity-linked bonds, sovereign sustainable bonds and sustainability-linked bonds (Mejia-Escobar *et al.*, 2020). Moreover, South America is home to rich biodiversity and critical ecosystems—most notably the Amazon rainforest, often referred to as the “lungs of the Earth” (Mikkola, 2021)—but faces severe environmental pressures, such as deforestation, urbanization and fossil fuel dependency, contributing to rising CO<sub>2</sub> emissions and ecological degradation. The region’s economic structure, marked by natural resource dependency and varying levels of industrialization, offers a distinct context for examining the interplay between finance, innovation and sustainability. In addition, its diverse socio-economic conditions enable the exploration of heterogeneous effects of sustainability drivers, providing transferable insights for other developing regions.

Regarding the forthcoming sections of this paper, Section 2 reviews the existing literature, Section 3 details the methodology, Section 4 presents the results, Section 5 discusses the study findings and Section 6 concludes with policy implications.

## 2. Literature review

### 2.1 Green finance and environmental sustainability

GFIN has become a vital tool for mitigating environmental degradation by channeling funds into sustainable projects, such as renewable energy (REN), energy efficiency and conservation (Sharif *et al.*, 2022). Theoretically, GFIN internalizes environmental externalities by promoting eco-friendly investments and discouraging polluting activities through mechanisms such as green bonds, CO<sub>2</sub> pricing and REN subsidies (Miyan *et al.*, 2024). Empirical studies support its effectiveness in reducing CO<sub>2</sub> emissions and fostering cleaner energy transitions (Sethi *et al.*, 2024). For instance, financing REN can significantly reduce CO<sub>2</sub> emissions by substituting fossil fuels (Gul and Hussain, 2024), while green bonds promote investment in low-carbon infrastructure. However, criticisms highlight limitations such as greenwashing, where labeled projects fail to achieve real environmental benefits (Shi *et al.*, 2023; Zhang, 2023) and the unequal distribution of GFIN, which can worsen inequalities and prioritize short-term visible gains over structural sustainability needs (Taghizadeh-Hesary and Yoshino, 2019, 2020). Building on the existing literature, this study proposes the following hypothesis.

- H1. Green finance (GFIN) has a significant negative impact on CO<sub>2</sub> emissions,, contributing to environmental sustainability.

### 2.2 Green innovation and environmental degradation

Green innovation involves developing and applying new technologies, processes, or systems that reduce environmental harm and promote sustainability, including advances in REN, waste management and eco-friendly designs (Rupasinghe *et al.*, 2024). Empirical studies largely support its favorable environmental impact. Innovations such as solar panels, wind turbines and bioenergy systems have helped reduce fossil fuel reliance and CO<sub>2</sub> emissions (Fu and Zhu, 2023; Jian and Afshan, 2022; Popp *et al.*, 2010). Similarly, energy-efficient appliances and processes have minimized environmental damage (Razzaq *et al.*, 2021; Sethi *et al.*, 2024), while green urban infrastructure further reduces ecological footprints (Rupasinghe *et al.*, 2024; Sharif *et al.*, 2022). However, challenges remain. The “rebound effect” may offset environmental gains when efficiency leads to greater consumption (Guan *et al.*, 2023). High costs, long development times (Losacker *et al.*, 2023), unequal access (Peimani, 2019), weak

intellectual property rights, fragmented policies and limited R&D incentives (Popp, 2019) also constrain effectiveness. Based on this discussion, this study proposes the following hypothesis.

- H2. Green innovation (GTI) has a significant negative impact on CO<sub>2</sub> emissions, contributing to environmental sustainability.

### 2.3 Economic growth and environmental sustainability

The EKC hypothesis suggests an inverted U-shaped relationship between economic growth and environmental degradation, where environmental harm increases in the early stages of growth and then declines after reaching a certain income level (Grossman and Krueger, 1995; Gul and Hussain, 2024; Han and Jun, 2023). This pattern is explained through increased investment in clean technologies, structural shifts from industry to services and stronger regulations at higher income levels (Stern, 2017; Pata, 2021; Lau *et al.*, 2018). However, the EKC is widely debated. Critics argue that its validity varies by pollutant and region and that CO<sub>2</sub> reductions do not reflect broader degradation, including biodiversity loss or deforestation (Smulders *et al.*, 2014; Ma *et al.*, 2023). Others note that reliance on market mechanisms neglects institutional weaknesses and inequality in developing nations (Shahbaz and Sinha, 2019; Adebayo *et al.*, 2023). Moreover, GLO and the rebound effect may shift pollution abroad or offset efficiency gains (Guan *et al.*, 2023; Bekun *et al.*, 2023; Ozturk *et al.*, 2023). Based on this, the following hypothesis is proposed.

- H3. The EKC hypothesis is supported in the seven South American countries.

### 2.4 Renewable energy and environmental sustainability

Renewable energy is central to mitigating environmental degradation and addressing climate change by offering low-emission alternatives to fossil fuels through sources such as solar, wind, hydro and bioenergy (Feng, 2022; Aktaş, 2021). Its integration into the energy mix significantly reduces CO<sub>2</sub> emissions and supports long-term sustainability (Gielen *et al.*, 2019; Khan *et al.*, 2024; Pata, 2021). Moreover, REN fosters socio-economic development by creating jobs and enhancing energy security through reduced reliance on fossil fuel imports (Mahjabeen *et al.*, 2020; Sachs *et al.*, 2019). Coupled with smart grid technologies, it improves efficiency and minimizes energy waste (Sharif *et al.*, 2024). However, challenges remain. Large-scale projects may disrupt ecosystems, causing biodiversity loss and displacing communities (Ma *et al.*, 2023). Intermittency issues often require fossil-based backup or resource-intensive storage solutions, while the extraction of critical materials such as lithium raises environmental and ethical concerns (Zhao *et al.*, 2022). High costs, infrastructure gaps and weak regulatory frameworks also hinder adoption in developing regions, especially in South America (Peimani, 2019; Oryani *et al.*, 2021; Gajdzik *et al.*, 2023). These barriers highlight the need for integrated policies and sustainable practices to fully harness the potential of REN.

### 2.5 Non-renewable energy and environmental degradation

NRE, primarily sourced from coal, oil and natural gas, remains the predominant driver of global energy consumption despite its severe environmental impacts (Falcone, 2023; Arora *et al.*, 2018). Fossil fuel combustion is the leading contributor to greenhouse gas emissions, fueling climate change, air pollution and ecological degradation (IPCC, 2022). Moreover, extraction activities such as drilling and mining result in habitat destruction, soil contamination and water pollution (Saleem *et al.*, 2020). Beyond environmental damage, reliance on finite fossil fuel resources threatens long-term energy security and economic stability (Armaroli and Balzani, 2007; McCollum *et al.*, 2014). Infrastructure related to fossil fuels, including pipelines and refineries, introduces additional ecological risks such as oil spills

and methane leaks. Economically, fossil fuel subsidies distort energy markets, hindering the transition to cleaner alternatives (McCollum *et al.*, 2014). Socially, the benefits of fossil fuel exploitation often accrue to a limited number of stakeholders, while marginalized communities disproportionately suffer the environmental and health consequences (Alarcón, 2023; Falcone, 2023). These multifaceted impacts underline the urgent need for a global shift toward sustainable energy practices.

### *2.6 Globalization and environmental sustainability*

Globalization, marked by intensified economic, cultural and societal interconnectedness, has produced complex effects on environmental sustainability. On the positive side, GLO facilitates the diffusion of green technologies, the best environmental practices and global cooperation through agreements such as the Paris Agreement (Karedla *et al.*, 2021; Sharif *et al.*, 2024). It fosters the adoption of energy-efficient solutions, REN technologies and ESG-driven corporate behaviors (Koengkan and Fuinhas, 2022). Additionally, information flows under GLO enhance environmental awareness and advocacy. However, GLO has also accelerated environmental degradation. Increased production, consumption and resource extraction have led to higher CO<sub>2</sub> emissions, particularly through expanded international trade and transportation (Bekun *et al.*, 2023). The “pollution haven” hypothesis suggests that GLO shifts pollution-intensive industries to developing countries with relatively weak environmental standards (Shahbaz *et al.*, 2016). Furthermore, GLO-induced economic growth has intensified deforestation, resource depletion and habitat destruction, notably in regions such as the Amazon (Mikkola, 2021; Adeleye *et al.*, 2023). Global consumer demand and lifestyle changes have also amplified ecological footprints, exacerbating environmental pressures. Thus, while GLO offers tools for environmental improvement, it simultaneously poses substantial risks to ecological sustainability.

### *2.7 Population and environmental sustainability*

Population growth remains a fundamental driver of environmental degradation, primarily through increased resource demand, waste generation and ecosystem strain. Larger populations intensify the consumption of food, water, energy and land, leading to deforestation, soil depletion and freshwater scarcity (Adeleye *et al.*, 2023; Ehrlich and Holdren, 1971). Urban expansion, spurred by population growth, often results in habitat destruction and elevated greenhouse gas emissions from transportation and construction activities. Furthermore, rising population densities exacerbate waste generation, contributing to pollution, particularly in regions with inadequate waste management systems. Developing countries face heightened environmental pressures as rapid urbanization and high fertility rates amplify resource depletion (Mikkola, 2021). In South America, population-driven agricultural expansion has significantly contributed to Amazonian deforestation, undermining biodiversity and carbon sequestration efforts. However, technological innovation and urban planning offer pathways to mitigate these effects. Energy-efficient housing, REN adoption, enhanced public transport and education and family planning initiatives can help lower the ecological footprint of growing urban populations (Martínez-Zarzoso and Maruotti, 2011). Thus, while population growth poses substantial environmental challenges, its impacts can be moderated through strategic interventions.

## **3. Method**

### *3.1 Data and variables*

This study uses panel data from seven South American countries for the period 2000–2020. Data for GFIN and GTI are sourced from the Organization for Economic Co-operation and Development (OECD), NRE from the US Energy Information Administration, GLO from the

### 3.2 Econometric model

This study employs a panel data to analyze the impact of GFIN, green innovation and key economic factors on CO<sub>2</sub> emissions in seven South American countries during 2000–2020, following framework from the IPAT and STIRPAT models. The STIRPAT approach allows for a stochastic examination of environmental impact, extending the deterministic IPAT framework. A log-linear (ln) econometric model (see equation 1) is adopted, offering key benefits such as linearization of nonlinear relationships, elasticity-based interpretation, variance stabilization and improved data normality.

$$\ln(CO_2)_{it} = \beta_0 + \beta_1 \ln(GFIN)_{it} + \beta_2 \ln(GTI)_{it} + \beta_3 \ln(GDP)_{it} + \beta_4 \ln(GDP^2)_{it} + \beta_5 \ln(REN)_{it} + \beta_6 \ln(NRE)_{it} + \beta_7 \ln(GLO)_{it} + \beta_8 \ln(POP)_{it} + \varepsilon_{it} \quad (1)$$

Where GFIN, GTI, GDP, REN, NRE, GLO and POP represent GFIN, green innovation, economic growth, REN use, NRE, globalization and population growth, respectively.  $\beta_0$  denotes the intercept, while  $\beta_1 - \beta_8$  represent the coefficients of the explanatory variables. The error term ( $\varepsilon$ ) captures unobserved heterogeneity. The expected coefficients' are negative for GFIN, GTI and REN, indicating their potential to reduce CO<sub>2</sub>, while positive for GDP, NRE, GLO and POP, reflecting their expected contribution to environmental degradation. A negative coefficient for GDP<sup>2</sup> supports the existence of the EKC.

### 3.3 Diagnostics procedures

Panel data analysis involves several complex aspects. Initially, this study conducted descriptive statistics to understand the central tendency, dispersion and distribution of the variables. More specifically, the Skewness-Kurtosis (SK) and Jarque-Bera (JB) tests are applied to gain insights into the data normality. This step is critical to identify any potential data anomalies and understand variable behavior across the sample countries and years to determine the appropriate econometric models. Subsequently, cross-sectional dependence (CD) among the countries is tested using the Pesaran (2004) CD test. This test assesses whether cross-sectional units are correlated, which is crucial for ensuring robust inference in panel data

**Table 1.** Variable measurement and data sources

Symbol	Measure	Unit	Source
CO <sub>2</sub>	Total carbon emissions/total population	Metric ton	WDI
GFIN	Global climate finance (constant 2019 USD)	USD	OECD-DAC
GTI	Development of environment-related technologies, % of all technologies	Percentage	OECD
GDP	GDP per capita (constant 2019 USD)	USD	WDI
GDP <sup>2</sup>	Square of GDP	USD	Authors' calculation
REN	Renewable energy consumption (% of total energy consumption)	Percentage	WDI
NRE	Non-renewable energy usage (total consumption) for oil, petroleum and natural gas	Quad Btu	EIA
GLO	Combined effect of globalization (economic, social and political)	Index	KOF Institute
POP	Population growth rate	Percentage	WDI

**Note(s):** WDI world development indicators, OECD Organization for Economic Co-operation and Development, DAC development assistance committee, EIA US energy information administration

**Source(s):** Authors' own estimates

analysis. In addition, the Pesaran and Yamagata (2008) slope heterogeneity (SH) test is applied to evaluate whether the coefficients vary across countries. This test is essential for validating the appropriateness of the econometric models under the assumption of heterogeneity among cross-sections. Given the presence of CD, second-generation unit root tests, specifically the cross-sectional Im, Pesaran and Shin (CIPS) and cross-sectional augmented Dickey-Fuller (CADF) tests, are employed to determine the stationarity of the variables. These tests are suitable for datasets with CD and heterogeneous panels. Finally, the Westerlund (2007) panel co-integration test was used to examine the existence of a long-term equilibrium relationship among the variables, considering both CD and SH.

### 3.4 Panel coefficient estimations

The MMQR model was adopted to capture the heterogeneity in the relationship between CO<sub>2</sub> and the explanatory variables across different quantiles. This method allows for the estimation of median-based coefficients, providing a more nuanced understanding of the relationships under varying levels of environmental stress. To validate the robustness of the results obtained from MMQR, Bootstrap Quantile Regression (BSQR) was performed. This method enhances the reliability of the estimates by addressing potential sampling variability. Additionally, to estimate the long-run relationship among the variables, static panel techniques, including feasible generalized least squares (FGLS) and panel corrected standard errors (PCSE), are employed. These methods address issues of autocorrelation, heteroscedasticity and CD, ensuring reliable coefficient estimates.

### 3.5 Panel Granger causality test

Finally, the Dumitrescu-Hurlin (2012) Granger causality test was applied to identify causal relationships among the variables. This approach is suitable for panel datasets with CD and heterogeneous slopes, allowing for the detection of both unidirectional and bidirectional causality.

## 4. Results

This section begins with the descriptive statistics presented in Table 2.

Table 2 highlights significant variability across variables, with LGFIN (mean: 24.149) and LGDP (mean: 8.985) exhibiting substantial dispersion, reflecting heterogeneity in GFIN and economic growth among South American countries. Normality tests (JB and SK) indicate significant results for most variables, particularly LGTI, LGDP<sup>2</sup>, renewable

**Table 2.** Descriptive statistics

Variables	Mean	Std. Dev	Min	Max	Skew	Kurt	SKtest	JB	Obs
LCO <sub>2</sub>	0.796	0.418	-0.018	1.574	0.33	2.092	14.93***	7.708**	147
LGFIN	24.149	6.493	7.872	34.134	-0.489	2.396	8.53**	8.085**	147
LGTI	2.392	0.561	0.372	3.832	-0.612	3.671	9.99***	11.92***	147
LGDP	8.985	0.451	8.088	9.774	-0.034	1.862	32.91***	7.955**	147
LGDP <sup>2</sup>	15.464	2.632	6.309	18.895	-0.828	3.253	12.89***	17.18***	147
LREN	3.278	0.562	2.041	4.114	-0.703	2.364	12.95***	14.6***	147
LNRE	-0.445	1.12	-2.684	1.841	0.296	2.902	2.31	2.211	147
LGLO	4.17	0.1	3.871	4.344	-0.362	2.832	3.43	3.387	147
LPOP	0.892	0.342	0.02	1.403	-0.855	3.172	13.26***	18.09***	147

**Note(s):** \*\*\* $p < 0.01$ , \*\* $p < 0.05$ , \* $p < 0.1$

**Source(s):** Authors' own estimates

energy (LREN) and LPOP, suggesting non-normal distributions, potential outliers and skewness. LREN and non-renewable energy (LNRE) show contrasting skewness, emphasizing disparities in energy utilization. Globalization (LGLO) exhibits minimal variability, indicating uniform trade integration. Additionally, panel data issues are diagnosed in the following tables.

Table 3 presents the CD test results indicating significant dependence among most variables, with 1% significance level, except for LREN and LPOP, which exhibit insignificant CD. Since CD is mostly present among the variables, it is necessary to conduct the SH test to determine whether the panel coefficients are heterogeneous. The results are presented in Table 4.

Table 4 indicates significant variability in the relationships between the independent variables and the CO<sub>2</sub> emission across the countries studied. Both the Delta tilde and the Delta tilde adjusted statistics are highly significant at the 1% level. This confirms the presence of SH, suggesting that the effects of variables such as GFIN, green technology innovation and economic growth on CO<sub>2</sub> emissions are not uniform across the seven South American countries in the sample. Addressing heterogeneity and CD is essential for ensuring accurate and country-specific policy recommendations. Therefore, this study employs the panel unit root tests and long-run panel co-integration test that can adjust these issues in examining the stationarity and co-integration among the variables shown in the following Tables 4 and 5, respectively.

Table 5 presents the results of the panel stationarity tests using second-generation unit root tests proposed by Pesaran (2004) (CIPS and CADF), which reveal mixed stationarity properties across variables. At levels, most variables (e.g., LGFIN, LGTI, LGDP, LGLO) are stationary, as indicated by significant CIPS and CADF statistics. However, variables like LCO<sub>2</sub>, LGDP<sub>2</sub>, LREN, LNRE and LPOP are non-stationary at levels, but become stationary after first differencing, indicating that they are integrated of order one I (1).

Meanwhile, Table 6 reveals that the Westerlund (2007) co-integration test results indicate mixed evidence for long-run relationships among the variables. The P<sub>a</sub> and P<sub>t</sub> statistics are significant at the 1 and 5% levels, suggesting the presence of co-integration across panels. However, the G<sub>t</sub> statistic is marginally significant ( $p = 0.070$ ), while the G<sub>a</sub> statistic is insignificant ( $p = 0.392$ ). These results indicate that there is evidence of co-integration for some panel groups.

Table 7 reports the Method of MMQR analysis, which reveals nuanced relationships between LCO<sub>2</sub> emissions and its regressors across quantiles, providing insights into distributional heterogeneity. GFIN demonstrates a consistently negative and statistically significant effect on CO<sub>2</sub> emissions across all quantiles (Q10–Q90). Notably, the magnitude of this effect increases slightly at higher quantiles, implying that GFIN becomes more effective in

**Table 3.** Cross-sectional dependence (CD) test

Variable	CD-test	p-value
LCO <sub>2</sub>	15.430***	0.000
LGFIN	17.410***	0.000
LGTI	3.310***	0.001
LGDP	19.550***	0.000
LGDP <sup>2</sup>	9.010***	0.000
LREN	-1.090	0.275
LNRE	15.220***	0.000
LGLO	16.120***	0.000
LPOP	2.390**	0.017

**Note(s):** \*\*\* $p < 0.01$ , \*\* $p < 0.05$ , \* $p < 0.1$

**Source(s):** Authors' own estimates

**Table 4.** Testing for slope heterogeneity (SH)

	Statistics	<i>p</i> -value
Delta tilde	5.082***	0.0000
Delta tilde adjusted	7.022***	0.0000

**Note(s):** \*\*\* shows 1% significance level

**Source(s):** Authors' own estimates

**Table 5.** Panel stationarity test

Variable	CIPS		CADF	
	At level	At 1st diff	At level	At 1st diff
LCO <sub>2</sub>	-2.367**	-4.316***	-2.220	-3.042***
LGFIN	-3.587***	-	-3.042***	-
LGTI	-3.600***	-	-2.813***	-
LGDP	-2.831***	-	-3.108***	-
LGDP <sup>2</sup>	-1.339	-2.567**	-2.166	-2.856***
LREN	-1.755	-4.152***	-2.214	-3.003***
LNRE	-1.932	-3.404***	-2.333**	-2.635***
LGLO	-3.068***	-	-1.796	-4.149***
LPOP	-1.623	-2.966***	-1.882	-3.258***

**Note(s):** \*\*\**p* < 0.01, \*\**p* < 0.05, \**p* < 0.1

**Source(s):** Authors' own estimates

**Table 6.** Westerlund co-integration test

Statistics	Value	Z-value	<i>p</i> -value
G <sub>t</sub>	-2.805*	-1.480	0.070
G <sub>a</sub>	-12.586	-0.274	0.392
P <sub>a</sub>	-8.597***	-3.503	0.000
P <sub>t</sub>	-12.700**	-1.659	0.049

**Note(s):** \*\*\**p* < 0.01, \*\**p* < 0.05, \**p* < 0.1

**Source(s):** Authors' own estimates

reducing emissions under more carbon-intensive conditions, thereby reaffirming its environmental mitigation potential. In contrast, green innovation (GTI) exhibits a positive and significant impact on emissions, especially at the upper quantiles. This counterintuitive result suggests that, in high-emission contexts, green innovation may paradoxically contribute to increased emissions, potentially due to rebound effects or transitional inefficiencies during early stages of technological deployment. Furthermore, GDP shows a positive and highly significant association with CO<sub>2</sub> emissions across all quantiles, indicating that economic expansion in South America remains heavily reliant on carbon-intensive activities. However, the squared GDP term is largely insignificant, providing limited support for the EKC hypothesis. This suggests that the income threshold for achieving environmental improvement has not yet been reached in the region.

Moreover, REN use significantly reduces emissions throughout the entire distribution, as reflected in its consistently negative and statistically significant coefficients. This confirms the

**Table 7.** Method of moments quantile regression (MMQR)

Dependent variable: LCO <sub>2</sub>		Quantiles									
Regressors	Location	Scale	Q10	Q20	Q30	Q40	Q50	Q60	Q70	Q80	Q90
LGFIN	-0.0102*** (0.0022)	-0.0002 (0.0015)	-0.0099*** (0.0024)	-0.0099*** (0.0021)	-0.0100*** (0.0020)	-0.0101*** (0.0020)	-0.0101*** (0.0021)	-0.0103*** (0.0027)	-0.0103*** (0.0030)	-0.0104*** (0.0032)	-0.0104*** (0.0035)
LGTI	0.0650** (0.0258)	0.0041 (0.0170)	0.0586** (0.0278)	0.0604** (0.0246)	0.0625*** (0.0233)	0.0632*** (0.0235)	0.0644*** (0.0247)	0.0672** (0.0306)	0.0685** (0.0344)	0.0694* (0.0372)	0.0705* (0.0407)
LGDP	0.6491*** (0.0686)	-0.0203 (0.0452)	0.6808*** (0.0741)	0.6719*** (0.0654)	0.6613*** (0.0620)	0.6582*** (0.0627)	0.6523*** (0.0659)	0.6385*** (0.0815)	0.6319*** (0.0917)	0.6277*** (0.0989)	0.6223*** (0.1085)
LGDP <sup>2</sup>	0.0011 (0.0077)	0.0098* (0.0051)	-0.0142* (0.0083)	-0.0099 (0.0075)	-0.0048 (0.0070)	-0.0033 (0.0072)	-0.0005 (0.0075)	0.0061 (0.0092)	0.0093 (0.0102)	0.0113 (0.0109)	0.0139 (0.0121)
LREN	-0.2705*** (0.0273)	0.0164 (0.0180)	-0.2961*** (0.0294)	-0.2889*** (0.0262)	-0.2804*** (0.0247)	-0.2779*** (0.0251)	-0.2731*** (0.0263)	-0.2620*** (0.0325)	-0.2567*** (0.0364)	-0.2532*** (0.0392)	-0.2489*** (0.0431)
LNRE	0.0780*** (0.0121)	-0.0130 (0.0079)	0.0982*** (0.0130)	0.0925*** (0.0116)	0.0858*** (0.0110)	0.0838*** (0.0112)	0.0801*** (0.0117)	0.0713*** (0.0144)	0.0671*** (0.0160)	0.0644*** (0.0171)	0.0610*** (0.0189)
LGLO	1.1509*** (0.2197)	0.1683 (0.1447)	0.8885*** (0.2363)	0.9620*** (0.2109)	1.0498*** (0.1992)	1.0754*** (0.2022)	1.1238*** (0.2119)	1.2380*** (0.2612)	1.2924*** (0.2917)	1.3280*** (0.3135)	1.3722*** (0.3457)
LPOP	0.4487*** (0.0692)	0.1112** (0.0456)	0.2752*** (0.0736)	0.3239*** (0.0680)	0.3819*** (0.0636)	0.3988*** (0.0655)	0.4308*** (0.0680)	0.5063*** (0.0826)	0.5422*** (0.0902)	0.5657*** (0.0957)	0.5949*** (0.1076)
Constant	-9.2407*** (0.8662)	-0.7344 (0.5705)	-8.0956*** (0.9302)	-8.4167*** (0.8336)	-8.7998*** (0.7863)	-8.9114*** (0.7995)	-9.1226*** (0.8370)	-9.6208*** (1.0297)	-9.8584*** (1.1471)	-10.0133*** (1.2310)	-10.2062*** (1.3604)
Observations	147	147	147	147	147	147	147	147	147	147	147

**Note(s):** Standard errors in parentheses; \*\*\* $p < 0.01$ , \*\* $p < 0.05$ , \* $p < 0.1$

**Source(s):** Authors' own estimates

vital role of clean energy in mitigating environmental degradation. On the other hand, NRE consumption is positively associated with emissions across all quantiles, with a stronger effect at the lower quantiles, reinforcing evidence of its persistent environmental harm. Likewise, GLO exhibits a strong positive and increasing effect on emissions, particularly in higher quantiles, implying that deeper trade integration may aggravate environmental degradation due to industrial scaling and production-related externalities. Population growth also exerts a positive and significant influence on emissions, with intensifying effects observed at higher quantiles, highlighting the growing environmental pressure associated with demographic expansion. Taken together, the location effects from the MMQR results reveal the average directional impact of each variable on CO<sub>2</sub> emissions, particularly for GFIN, REN and GDP. In contrast, the scale effects underscore the changing intensity of these relationships, especially for variables like GLO and population, which demonstrate stronger impacts under conditions of higher emission volatility.

Additionally, the MMQR results are illustrated graphically in [Appendix A](#), providing clearer insights and reinforcing the robustness of the findings. The visualizations align with the numerical estimates, highlighting the heterogeneous effects of GFIN, innovation and control variables across different emission levels. To ensure reliability and validity, robustness checks were conducted using bootstrap quantile regression (BSQR), FGLS and PCSE. As shown in [Table 8](#), these alternative approaches produce consistent patterns and significance levels, further validating the MMQR results and aligning with existing literature on the environmental impacts of GFIN, energy use, GLO and economic growth.

[Table 9](#) reveals that the diagnostic tests confirm the reliability of the econometric model. The variance inflation factor (VIF) values, all below 10, indicate no severe multicollinearity ([Gujarati, 2022](#)). The Hausman test supports the fixed-effect model, accounting for country-specific heterogeneity. The Modified Wald test reveals heteroskedasticity, necessitating robust standard errors, FGLS, or PCSE estimators. The Wooldridge test confirms serial correlation, requiring similar corrections. These diagnostics validate the model's robustness and [Dumitrescu-Hurlin's \(2012\)](#) panel Granger causality test further explores causal relationships.

[Table 10](#) shows the panel Granger causality test results, which reveal varying causal relationships between LCO<sub>2</sub> and key economic and environmental variables. A bidirectional causality exists between CO<sub>2</sub> emissions and economic growth (LGDP), NRE consumption (LNRE) and population growth (LPOP), indicating mutual influence and highlighting the dynamic interplay between emissions, economic activity and demographic changes. Unidirectional causality is observed from CO<sub>2</sub> emissions to green finance (LGFIN), green innovation (LGTI) and renewable energy consumption (LREN), suggesting that worsening environmental conditions drive financial, technological and energy transition responses rather than vice versa. Additionally, globalization (LGLO) influences CO<sub>2</sub> emissions, but emissions do not significantly impact LGLO, reflecting the role of global economic integration in shaping environmental outcomes. No causality is found from emissions to GLO, suggesting that external trade and policy dynamics may drive carbon trends more than domestic emission levels.

## 5. Discussion

The findings, derived from the MMQR and validated through BSQR, FGLS and PCSE estimators, provide nuanced insights that challenge conventional assumptions and extend existing theoretical perspectives. The negative and statistically significant relationship between GFIN (LGFIN) and CO<sub>2</sub> emissions across all quantiles offers robust empirical support for Hypothesis H1. This outcome aligns with the theoretical premise that targeted financial mechanisms can drive environmental improvements by incentivizing clean energy investments, sustainable infrastructure and eco-friendly innovation ([Jian and Afshan, 2022](#)). This finding underscores the catalytic role of GFIN in transitioning toward low-carbon economies and highlights its effectiveness in both low- and high-emission contexts. Moreover,

**Table 8.** Robustness check using bootstrap quantile regression (BSQR), FGLS and PCSE models

Dep. Var: LCO <sub>2</sub> Regressors	Quantiles									FGLS	PCSE
	Q10	Q20	Q30	Q40	Q50	Q60	Q70	Q80	Q90		
LGFIN	0.0012 (0.0024)	-0.0021 (0.0030)	-0.0041 (0.0028)	-0.0051* (0.0029)	-0.0052* (0.0030)	-0.0079*** (0.0028)	-0.0071*** (0.0025)	-0.0068** (0.0027)	-0.0080** (0.0036)	-0.0056*** (-3.193)	-0.0102*** (-5.391)
LGTI	0.0098 (0.0246)	0.0180 (0.0285)	0.0023 (0.0276)	0.0108 (0.0268)	0.0197 (0.0318)	0.0496 (0.0353)	0.0676* (0.0359)	0.0645* (0.0349)	0.0248 (0.0354)	0.0448** (2.210)	0.0650*** (2.890)
LGDP	0.5258*** (0.0477)	0.5755*** (0.0597)	0.5876*** (0.0640)	0.6366*** (0.0689)	0.6033*** (0.0915)	0.5290*** (0.1081)	0.5818*** (0.1136)	0.5477*** (0.1185)	0.4551*** (0.1518)	0.566*** (9.165)	0.649*** (10.96)
LGDP <sup>2</sup>	-0.0020 (0.0067)	-0.0068 (0.0073)	-0.0031 (0.0070)	-0.0030 (0.0087)	0.0056 (0.0108)	0.0165 (0.0110)	0.0203* (0.0112)	0.0238** (0.0115)	0.0285* (0.0146)	0.00402 (0.500)	0.00106 (0.131)
LREN	-0.3632*** (0.0233)	-0.3433*** (0.0401)	-0.3029*** (0.0496)	-0.2557*** (0.0459)	-0.2357*** (0.0509)	-0.2253*** (0.0643)	-0.1980** (0.0761)	-0.2086*** (0.0779)	-0.2582*** (0.0909)	-0.293*** (-13.48)	-0.270*** (-11.18)
LNRE	0.0951*** (0.0125)	0.0936*** (0.0185)	0.0719*** (0.0215)	0.0577*** (0.0220)	0.0416* (0.0226)	0.0644*** (0.0224)	0.0483** (0.0206)	0.0455** (0.0196)	0.0516** (0.0233)	0.0675*** (7.191)	0.0780*** (6.769)
LGLO	0.2089 (0.3050)	0.4992 (0.3858)	0.8983** (0.4269)	1.1511*** (0.4235)	1.2821*** (0.3853)	1.3517*** (0.3067)	1.4013*** (0.2412)	1.3887*** (0.2226)	1.6721*** (0.2525)	1.098*** (5.693)	1.151*** (6.195)
LPOP	0.0174 (0.0771)	0.1123 (0.1554)	0.3357* (0.1835)	0.5091*** (0.1454)	0.5719*** (0.1197)	0.5758*** (0.1190)	0.6415*** (0.1238)	0.6285*** (0.1172)	0.5749*** (0.1387)	0.389*** (7.341)	0.449*** (8.731)
Constant	-3.7526*** (1.3687)	-5.3929*** (1.8905)	-7.4355*** (2.1557)	-9.2078*** (1.9221)	-9.7000*** (1.5883)	-9.4765*** (1.3083)	-10.3955*** (1.0398)	-10.0278*** (0.8585)	-10.0770*** (1.0003)	-8.259*** (-12.08)	-9.241*** (-14.59)
Observations	147	147	147	147	147	147	147	147	147	147	147

**Note(s):** Standard errors in parentheses; \*\*\* $p < 0.01$ , \*\* $p < 0.05$ , \* $p < 0.1$

**Source(s):** Authors' own estimates

**Table 9.** Postestimation diagnostic tests

Multicollinearity test	VIF	1/ VIF	Other diagnostic tests		Statistics	<i>p</i> -value
LGDP	7.039	0.142	Individual fixed effects	Hausman test	119.07***	0.0000
LGDP <sup>2</sup>	4.412	0.227	Time fixed effects	Testparm i.year	5.12**	0.0337
LGLO	3.44	0.291	Heteroskedasticity	Modified Wald test	25.98***	0.0005
LPOP	3.046	0.328	Serial (auto) correlation	Wooldridge test	50.920***	0.0004
LREN	1.825	0.548				
LNRE	1.644	0.608				
LGTI	1.574	0.635				
LGFIN	1.479	0.676				
Mean VIF	3.057	0.0				

**Note(s):** \*\*\**p* < 0.01; \*\**p* < 0.05; \**p* < 0.1  
**Source(s):** Authors' own estimates

**Table 10.** Dumitrescu–Hurlin panel Granger causality test results

Ho hypothesis	W-Stat	Z-stat	<i>p</i> -value	Remark
LCO <sub>2</sub> ≠ > LGFIN	4.0868***	5.7748	0.0000	LCO <sub>2</sub> → LGFIN
LGFIN ≠ > LCO <sub>2</sub>	1.6710	1.2552	0.2094	
LCO <sub>2</sub> ≠ > LGTI	2.5329***	2.8679	0.0041	LCO <sub>2</sub> → LGTI
LGTI ≠ > LCO <sub>2</sub>	1.0815	0.1525	0.8788	
LCO <sub>2</sub> ≠ > LGDP	4.4635***	6.4796	0.0000	LGDP ↔ LCO <sub>2</sub>
LGDP ≠ > LCO <sub>2</sub>	4.4927***	6.5342	0.0000	
LCO <sub>2</sub> ≠ > LREN	2.4924***	2.7920	0.0052	LCO <sub>2</sub> → LREN
LREN ≠ > LCO <sub>2</sub>	1.8632	1.6149	0.1063	
LCO <sub>2</sub> ≠ > LNRE	3.1204***	3.9670	0.0001	LNRE ↔ LCO <sub>2</sub>
LNRE ≠ > LCO <sub>2</sub>	1.9857*	1.8441	0.0652	
LCO <sub>2</sub> ≠ > LGLO	0.4557	-1.0183	0.3085	
LGLO ≠ > LCO <sub>2</sub>	3.9247***	5.4716	0.0000	LGLO → LCO <sub>2</sub>
LCO <sub>2</sub> ≠ > LPOP	4.1876***	5.9634	0.0000	
LPOP ≠ > LCO <sub>2</sub>	3.1971***	4.1104	0.0000	LPOP ↔ LCO <sub>2</sub>

**Note(s):** ≠ > Does not Granger cause; → unidirectional; and ↔ bidirectional. \*\*\**p* < 0.01; \*\**p* < 0.05; \**p* < 0.1  
**Source(s):** Authors' own estimates

the consistent significance across quantiles reflects the broad-based impact of GFIN, suggesting that its benefits are not limited to countries with relatively low emissions but are also crucial for economies with high environmental pressure. These findings reinforce the growing policy emphasis on sustainable finance taxonomies and green investment frameworks in emerging markets. Contrary to Hypothesis H2, green technology innovation (LGTI) exhibits a positive and significant effect on CO<sub>2</sub> emissions, particularly at higher quantiles. This unexpected outcome reveals the transitional paradox of green innovation, where early stages of technology adoption may inadvertently increase emissions due to industrial restructuring, energy rebound effects and the CO<sub>2</sub> footprint of innovation-related activities. This result is consistent with the rebound effect theory, which posits that efficiency gains can lead to increased consumption and emissions (Guan *et al.*, 2023). Similar conclusions are drawn in recent studies involving both developed (Razzaq *et al.*, 2021) and developing economies (Dunyo *et al.*, 2024), suggesting that innovation alone is insufficient unless complemented by regulatory enforcement, behavioral change and clean energy inputs. Therefore, while green innovation remains pivotal, its environmental benefits in South America may be delayed unless reinforced by systemic shifts in production and energy systems.

The results show a positive and significant association between GDP (LGDP) and CO<sub>2</sub> emissions, while the squared GDP term (LGDP<sup>2</sup>) lacks consistent significance across quantiles. These findings challenge the validity of the EKC hypothesis, meaning Hypothesis H3 is not supported in the South American context, where economic development has not yet reached the threshold needed for decoupling growth from environmental degradation. This outcome suggests that current growth trajectories in the region remain heavily dependent on carbon-intensive sectors such as manufacturing, extractive industries and fossil-fuel-based energy. The absence of a turning point in the EKC curve implies that environmental deterioration continues alongside income growth, emphasizing the need for structural reforms, clean energy transitions and green industrial policies to achieve sustainable development.

Consistent with theoretical expectations, renewable energy consumption (LREN) is found to significantly reduce emissions across quantiles, validating its role as a cornerstone of decarbonization strategies. This finding supports the literature emphasizing the environmental superiority of renewables in emerging economies (Apergis and Payne, 2010). Conversely, LNRE is positively associated with emissions, reaffirming its environmental externalities. The stark contrast between LREN and LNRE reinforces the importance of accelerating the shift from fossil fuels to clean energy. It also highlights the region's dual energy challenge, expanding access to energy while minimizing ecological harm. Meanwhile, the positive impact of globalization (LGLO) on CO<sub>2</sub> emissions, especially in higher quantiles, reflects the environmental burden-shifting hypothesis. Global trade and investment flows, while beneficial for economic growth, may intensify carbon footprints in host countries, particularly when environmental regulations are weak or inconsistently enforced (Shahbaz *et al.*, 2013). This supports concerns that developing economies may become pollution havens, attracting carbon-intensive industries due to relatively weak environmental standards. Policymakers in South America must therefore balance the benefits of trade openness with stringent environmental governance to mitigate the adverse ecological consequences of GLO.

The consistent and significant positive relationship between population growth (LPOP) and emissions across quantiles reinforces the IPAT identity (Ehrlich and Holdren, 1971), which attributes environmental impact to population, affluence and technology. Larger populations increase energy demand, transportation needs and urbanization, thereby intensifying emissions. This finding is particularly relevant for urban planning and sustainable development strategies. South American policymakers must incorporate population dynamics into climate policy, focusing on energy-efficient urban infrastructure, public transportation and sustainable consumption models.

The Granger causality tests further illuminate the directionality of relationships. The bidirectional causality between CO<sub>2</sub> emissions and economic growth, NRE and population suggests mutual reinforcement, indicating that environmental degradation and macroeconomic variables are deeply intertwined. Meanwhile, unidirectional causality from emissions to GFIN, green innovation and REN suggests that environmental stress may prompt corrective financial and technological responses rather than these factors preemptively reducing emissions. This reactive pattern implies a gap in proactive environmental policy. To move toward sustainability, governments must embed GFIN and innovation as leading strategies, not just responses to crisis-level degradation.

## 6. Conclusions

Primarily driven by CO<sub>2</sub> emissions, environmental degradation remains a critical challenge for developing economies, particularly in South America, as they strive to balance economic growth with sustainability. Despite the global emphasis on GFIN and innovation as tools for mitigating CO<sub>2</sub> emissions, evidence from developing countries is limited, especially from South America, creating a significant research gap. This study analyzed panel data from seven South American countries (2000–2020) using the Method of MMQR model, where CO<sub>2</sub> emissions (a proxy for environmental degradation) were modeled as a function of GFIN, green

innovation (GTI), economic growth (GDP), REN, NRE, GLO and population (POP). The findings reveal that GFIN significantly reduces CO<sub>2</sub> emissions, particularly in high-pollution contexts, while green innovation showed unexpected results, reflecting potential inefficiencies or rebound effects. Economic growth positively contributes to emissions, with limited evidence supporting the EKC hypothesis, highlighting the need for policies that decouple growth from environmental harm. Renewable energy demonstrated a significant reduction in emissions, whereas NRE and GLO exacerbated environmental degradation. Population growth also had a positive effect on emissions, emphasizing its role in shaping sustainability outcomes. These findings are robust and consistent with the BSQR, FGLS and PCSE models. Additionally, the Dumitrescu-Hurlin test reveals bidirectional causality between CO<sub>2</sub>, GDP, NRE and POP, and unidirectional causality from CO<sub>2</sub> to GFIN, GTI and REN, highlighting dynamic interactions.

The findings of this study provide several key policy implications for South American countries striving to achieve environmental sustainability. First, policymakers should prioritize the promotion of GFIN mechanisms, such as green bonds and sustainable investment funds, as they are effective in reducing CO<sub>2</sub> emissions, especially in high-pollution scenarios. Second, to maximize the impact of green innovation, governments should invest in research and development (R&D), improve technological efficiency and create incentives to ensure that green technologies deliver the intended environmental benefits without triggering rebound effects. Third, the limited evidence for the EKC suggests the need for proactive policies that decouple economic growth from environmental degradation by promoting low-carbon industries, enhancing energy efficiency and implementing strict environmental regulations. Fourth, the significant role REN in reducing emissions highlights the urgency of scaling up investments in REN infrastructure and technologies while phasing out reliance on NRE sources through carbon pricing and subsidies for clean energy. Additionally, while globalization may foster economic growth, it can lead to environmental harm; thus, countries should adopt sustainable trade practices and environmental standards for international agreements. Lastly, addressing the positive impact of population growth on emissions requires policies that promote sustainable urbanization, improve energy efficiency in housing and transportation and integrate environmental education into development planning. Collectively, these measures will enable South American countries to align economic growth with environmental protection and accelerate their progress toward achieving the Sustainable Development Goals.

While this study provides valuable insights, it is not without limitations. First, it focuses solely on seven South American countries over the period 2000–2020, which may limit the generalizability of the findings to other regions or income groups. Future research could expand the scope to include a broader range of countries or conduct comparative analyses across different economic blocs to gain a more comprehensive understanding of the dynamics of GFIN, green innovation and environmental sustainability. Second, the study uses panel data econometric models, although it accounts for potential endogeneity issues (Machado and Silva, 2019). Future studies could employ dynamic econometric techniques, such as instrumental variables or dynamic panel models, to address this concern. Third, while CO<sub>2</sub> emissions are used as the primary measure of environmental degradation, additional indicators such as ecological footprints, biodiversity loss, water pollution, or deforestation could provide a more holistic view of environmental sustainability. Fourth, the study does not explicitly account for the role of institutional quality or governance in shaping the effectiveness of GFIN and innovation policies. Including such factors in future research could offer deeper insights into the enabling conditions for sustainable development. Lastly, this study assumes a linear relationship in some cases, while future research could explore potential nonlinearities or threshold effects in the relationships between the variables.

#### Supplementary material

The supplementary material for this article can be found online.

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