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The impact of economic globalisation on growth and environmental quality in the countries of the Andean Community

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The influence of economic globalisation on growth and environmental quality in the countries of the Andean Community

This study analyses the relationship between the main channels of economic globalisation, economic growth and environmental quality in Bolivia, Colombia, Ecuador and Peru—member countries of the Andean Community (CAN)—during the period 1990–2025. A quantitative, longitudinal and non-experimental approach is employed, based on a panel of 144 country-year observations. Using two autoregressive distributed lag models for panel data (Panel ARDL), estimated using the Pooled Mean Group (PMG) method, the relationships between exports, imports, foreign direct investment (FDI), passenger air transport, remittances and renewable energy consumption, on the one hand, and real gross domestic product and CO_2 emissions, on the other, are examined, distinguishing between the short- and long-term horizons. The results show positive and statistically significant associations between imports, FDI and air transport and economic growth in the short term, whilst no significant individual coefficients were identified in the long term. From an environmental perspective, air transport shows a positive association with CO_2 emissions in both the short and long term, whilst renewable energy consumption maintains a negative and significant relationship, particularly in the long term. The other variables do not show statistically significant environmental associations in the aggregate estimates. These findings demonstrate that the channels of international integration have distinct economic and environmental relationships, highlighting the need to coordinate strategies for international integration with policies on energy efficiency and environmental sustainability within the Andean Community (CAN).

Keywords: economic globalisation; economic growth; environmental quality; Andean Community; renewable energy; ARDL panel

1. Introduction

Economic globalisation has progressively transformed the conditions under which national economies participate in production, trade and the international flow of capital and resources. The intensification of these links has expanded opportunities for growth

and productive diversification, although the outcomes continue to vary across countries with different economic structures and adaptive capacities. Evidence from Asian economies shows that the relationship between liberalisation, international integration and economic performance depends on the specific characteristics of each country (Ojaghlou & Tercan, 2024). This heterogeneity is also observed in Latin America and the Caribbean, where the various dimensions of globalisation and economic freedom are associated with growth in different ways (Santiago et al., 2020). However, the implications of greater international integration extend beyond productive performance, as the expansion of economic activities can intensify energy consumption, the use of natural resources and environmental pressures. From this perspective, the sustainability of growth associated with globalisation is a growing concern for economies seeking to reconcile international competitiveness with sustainable development (Sandoval et al., 2022). Research carried out in South Asia highlights the interdependence between globalisation, growth and environmental degradation (Kiani et al., 2021), whilst heterogeneous panel analyses identify significant differences in the relationships between economic integration and environmental quality (Lv & Xu, 2018). This background highlights that the economic benefits of globalisation do not, on their own, allow us to anticipate its environmental consequences, which necessitates a joint examination of both dimensions of development.

The heterogeneity of these results highlights the need to analyse globalisation on the basis of its specific transmission mechanisms, particularly those linked to international trade and foreign direct investment (FDI) flows. Trade expansion can promote growth through greater market opportunities, productive specialisation and access to intermediate goods, although it can also increase emissions when economic activity is concentrated in energy-intensive sectors. Evidence from the economies of the

former North American Free Trade Agreement (NAFTA) identifies significant relationships between economic globalisation and carbon dioxide (CO_2) emissions, highlighting the environmental pressures associated with greater openness (Kalaycı & Hayaloğlu, 2019). However, these relationships may vary depending on the energy structure of economies, particularly when the use of renewable energy sources plays a role in production and growth processes (Ali et al., 2022). Furthermore, FDI constitutes a mechanism for integration that can expand productive capacity, facilitate the adoption of technologies and alter the operating conditions of economic sectors. Its environmental implications, however, are not necessarily uniform, as demonstrated by evidence from South Korea on the evolution of the relationship between foreign investment and emissions during different stages of economic development (Kim & Seok, 2023). In the Latin American context, research also identifies spatial differences in the associations between trade, foreign investment and emissions (Mahmood, 2023), as well as heterogeneous effects of international capital flows on environmental quality (Ochoa-Moreno et al., 2021). Consequently, a joint analysis of trade and FDI allows us to move beyond an aggregate interpretation of globalisation and to recognise that its links with economic growth and environmental performance may stem from distinct mechanisms.

Although trade and foreign investment are central dimensions of economic integration, growing international interdependence is also manifested through the mobility of people and cross-border transfers of income. Passenger air transport represents a component of international connectivity that facilitates tourism, trade and service activities, contributing to the integration of markets and the generation of economic activity. However, its relationship with growth depends on market conditions and the characteristics of the economies involved (C. Van Nguyen, 2024). At the same

time, the expansion of the aviation sector poses environmental challenges stemming from its energy demand, as evidenced by the analysis of the links between air transport and CO_2 emissions in the G20 economies (Habib et al., 2022). International remittances constitute another mechanism through which globalisation operates, although they function primarily by transferring resources to recipient households, with potential effects on consumption, saving and investment. Their contribution to growth has been examined in middle-income economies, highlighting their link to other factors associated with productive performance (Islam et al., 2024). However, their environmental implications may vary depending on how the income is used and on the structural conditions of the countries concerned; non-linear relationships between remittances and emissions have been identified in southern African economies (Biyase et al., 2024). In Latin America, the evidence links these flows to capital formation, structural transformation and economic growth (Zurita Moreano et al., 2024). Consequently, incorporating air transport and remittances broadens our understanding of globalisation beyond its traditional commercial and financial dimensions, whilst also allowing us to examine whether these forms of interdependence have distinct associations with economic and environmental performance.

The relationship between these dimensions of globalisation takes on particular relevance when considering the energy mix of economies, given that the consumption of renewable energy can alter the conditions under which productive expansion is linked to CO_2 emissions. International literature has examined the interactions between economic globalisation, financial development, renewable energy consumption and environmental performance, suggesting that these relationships should be interpreted from a multidimensional perspective (Hosan et al., 2026). Furthermore, evidence on economic growth, renewable energy and emissions identifies dynamic links that

challenge the assumption that productive expansion and the energy transition evolve independently (Koiry et al., 2026). Research carried out in the BRICS countries further incorporates institutional quality as a key factor in understanding the relationships between globalisation and green growth (Neffati & Khemiri, 2025), whilst comparative studies between economies with different levels of sustainability reveal divergent trajectories of economic development and environmental performance (Teixeira et al., 2025). In Latin America, research on the countries of the Pacific Alliance provides insights into these interactions within a regional context of growing economic integration (Gómez Sánchez Torres et al., 2026). Despite these advances, there remains a gap in our comprehensive understanding of the relationships between the various channels of globalisation, renewable consumption, economic growth and CO_2 emissions in the economies of the Andean Community. In particular, longitudinal evidence that simultaneously incorporates international trade, FDI, passenger air transport and remittances remain limited for Bolivia, Colombia, Ecuador and Peru. This shortcoming is particularly significant because the differences in production, trade and energy between these countries may influence the magnitude and direction of the relationships under examination. Consequently, a quantitative approach is required to test hypotheses regarding the links between these variables and to distinguish between their short- and long-term associations, thereby providing empirical evidence on the economic and environmental dimensions of Andean international integration.

In response to this gap, the overall objective of this study is to analyse the relationships between the main channels of economic globalisation and renewable energy consumption, on the one hand, and economic growth and environmental quality in the member countries of the Andean Community (CAN) during the period 1990–2025, on the other. Specifically, it seeks to: (i) examine the relationship between

international trade, FDI, passenger air transport and remittances and real gross domestic product (GDP); (ii) assess the association between these factors and CO_2 emissions, used as a proxy for environmental quality; and (iii) determine the relationship between renewable energy consumption and both outcomes, distinguishing between the short and long term. The article takes as its analytical reference the study by Q. H. Nguyen (2024), which examines the factors of globalisation, growth and environmental quality in South-East Asia; however, we do not assume that its results will be replicated in the Andean economies. We use publicly available annual secondary data from Bolivia, Colombia, Ecuador and Peru, and two distributed lag autoregressive panel (ARDL) models—one for real GDP and the other for CO_2 emissions. Our contribution lies in disaggregating external integration, simultaneously evaluating two outcomes of public interest, and providing comparable evidence for a region with diverse productive and energy structures. The remainder of the article is organised as follows. Section 2 presents the theoretical framework underpinning the relationships between economic globalisation, growth and environmental quality, whilst Section 3 sets out the research hypotheses. Section 4 describes the methodological design, the variables and the econometric strategy employed. Section 5 presents the results of the ARDL panel models, followed by Section 6, which discusses the findings in the light of the existing literature. Finally, Section 7 presents the conclusions, recommendations, limitations and future lines of research.

2. Theoretical framework

2.1. Economic integration, growth and environmental quality

The relationship between globalisation and sustainability can be analysed through three mechanisms: scale, composition and technology. The scale effect arises when increased

production requires more energy, transport or materials and, with technology held constant, leads to increased pollution. The composition effect depends on the sectors in which the economy specialises: the expansion of emission-intensive activities can deteriorate environmental quality, whilst a growing share of less polluting activities could improve it. Finally, the technical effect refers to the capacity of innovation, efficiency and regulation to reduce environmental intensity per unit produced. These mechanisms help to explain why growth and emissions do not necessarily maintain a constant relationship throughout the development process. Analyses of the Kuznets environmental curve have examined the possibility of non-linear relationships between economic expansion and environmental degradation, although this does not automatically imply the existence of a turning point in all economies (Prasetyanto & Sari, 2021). In countries with high emissions, the link between growth and CO_2 has also been studied, highlighting that environmental costs constitute a dimension of macroeconomic performance (Azam et al., 2016). The interaction between energy consumption, the pollution haven hypothesis and the Kuznets curve shows that the type of energy and the productive structure are central to interpreting the results (Li et al., 2022). Similarly, research on ecological sustainability in African economies incorporates globalisation and renewable energy consumption to assess whether energy sources can alter the environmental pressure associated with growth (Abdi et al., 2025). Analyses of institutional quality also highlight its relationship with long-term environmental performance (Mohamed et al., 2025). This perspective allows real GDP and CO_2 emissions to be treated as two conceptually distinct outcomes: the former represents the volume of economic activity, whilst the latter approximates a specific, non-exhaustive dimension of environmental quality.

2.2. International trade: exports and imports

Foreign trade integrates countries through two complementary, yet economically distinct, flows. Exports expand the potential demand for domestic firms and can foster economies of scale, specialisation and external revenue; imports facilitate access to capital goods, inputs and technologies, whilst also reflecting domestic demand and conditions of competitiveness. Consequently, trade openness—understood as an aggregate measure of the intensity of trade—does not fully capture the information provided by each of these flows. The diversity of imported inputs may be linked to output growth by expanding the productive combinations available to firms (Yu & Meng, 2023). In middle-income economies, trade and FDI have been studied alongside productivity as components linked to growth, highlighting that openness does not operate independently of productive capacities (Duong et al., 2022). For the ASEAN-5, research on economic openness indicates that its effects require consideration of differences between countries (Prawoto & Nurhanifah, 2025). From an environmental perspective, exports and imports can alter energy use and sectoral allocation, whilst access to more efficient machinery can enhance the technical effect. A study combining growth, energy intensity, environmental taxes and trade openness illustrates the relevance of policies and energy use in this relationship (Kostakis et al., 2025). More generally, trade liberalisation and FDI flows have been analysed in conjunction with environmental quality and growth, highlighting the need to interpret their effects within specific economic contexts (Hakimi & Hamdi, 2016). In the models used in this research, distinguishing between exports and imports allows us to capture specific associations, even when the hypotheses are expressed under the general concept of international trade.

2.3. Foreign direct investment and the structure of production

FDI constitutes a channel for the international flow of capital and entrepreneurial capabilities, the potential impact of which on GDP depends on its volume, composition and integration with the local productive sector. Investments can finance new facilities and processes, generate employment and facilitate technological learning; however, their impact may be limited if the activities have few linkages or if institutions restrict their utilisation. Evidence from African economies examine FDI and trade openness jointly as factors linked to growth (Chibalamula et al., 2023). Studies in the BRICS countries also find links between foreign capital, trade and economic performance, although these should not be assumed to be identical across countries (Banday et al., 2021). The role of economic freedom has been studied as a condition that modifies the link between FDI and growth (Shokhrukh et al., 2023). Furthermore, institutional quality is a key factor in interpreting the economic contribution of foreign investment in ASEAN economies (B. C. X. Nguyen & Ho, 2025). A provincial and sectoral analysis of Indonesia highlights that the effects of FDI can differ considerably depending on the location and type of recipient activity (Fazaalloh, 2024). These distinctions are also significant for the environment: international capital can increase the scale of emission-intensive activities or drive the replacement of outdated technologies. Thus, FDI should not be conceptualised as an automatic driver of modernisation, but rather as a flow whose relationship with growth and pollution depends on the recipient sectors and the economic conditions that either favour or limit its effects.

2.4. Foreign capital and pollution mechanisms

The environmental dimension of FDI has been explained primarily through the ‘refuge’ and ‘pollution halo’ hypotheses. The former posits that regulatory differences favour the

localisation of polluting activities where compliance costs are lower; the latter emphasises the potential for transferring technologies, standards and capabilities that reduce emissions per unit produced. Research in Central and Eastern European economies have investigated whether foreign capital is linked to environmental degradation, providing evidence to test the 'refuge' hypothesis (Christoforidis & Katrakilidis, 2022). Analysis of the ASEAN-5 countries has also re-examined this hypothesis using panel data (Guzel & Okumus, 2020). However, this relationship cannot be viewed in isolation from economic development: international evidence shows that the impact of foreign investment on emissions can vary across different levels of income and development (Abdullahi et al., 2023). A study incorporating GDP per capita into the relationship between FDI and emissions highlights the importance of this factor in interpreting heterogeneous effects (Wang et al., 2023). Similarly, the causal link between globalisation and FDI has been examined for African countries, showing that the relationship between external integration and capital flows is not necessarily unidirectional (Aluko et al., 2021). In the CAN, where productive structures exhibit significant differences, this background justifies an empirical assessment of the sign of the relationship between FDI and CO_2 without a priori equating foreign investment with pollution or with environmental modernisation.

2.5. Air travel and remittances as channels of integration

The mobility of people constitutes a dimension of interdependence that cannot be reduced to trade in goods. Air transport facilitates business travel, tourism and connections between business networks, but its intensity also depends on income levels and infrastructure development. Therefore, the relationship with GDP can be bidirectional: improved connectivity can expand economic opportunities, whilst a more dynamic economy can increase demand for air services. An analysis of air transport and

emissions in G20 countries provides evidence that connectivity must also be assessed in terms of its environmental costs (Gül, 2025). In BRICS economies, the relationship between air transport and CO_2 has been examined using methods that account for variations across the emissions distribution (Gümüş Akar et al., 2026). Remittances, whilst also linked to international mobility, operate through household budgets rather than the supply of air transport services. Their relationship with savings, capital formation and growth may be non-linear, particularly in smaller emerging economies (Ait Benhamou & Cassin, 2021). Comparative evidence for North African countries shows that the relationships between remittances and growth differ according to the national context (Daoudi, 2026). Similarly, research on African economies distinguishes between the short- and long-term impacts of remittances and other external flows (Adugna Chomen et al., 2024). Conceptually, both channels connect territories and people but have different implications for economic activity and energy demand: transport involves operational emissions associated with mobility, whilst remittances can indirectly alter household consumption of goods, investment patterns and the adoption of technologies.

2.6. Renewable energy and the conceptual framework

Renewable energy consumption is incorporated as an energy dimension that allows for the study of the compatibility between economic expansion and lower emissions. Unlike trade, FDI or remittances, it is not in itself an international flow; it represents a condition of the energy mix that can interact with the productive opportunities created by global integration. Higher renewable consumption can help to replace conventional sources, although its capacity to reduce emissions depends on the generation mix and the growth in total demand. Analyses of renewable energy and environmental quality highlight possible asymmetric effects, whereby increases and decreases do not

necessarily produce equivalent responses (Tran, 2024). Evidence for Mexico has also dynamically examined the combined role of globalisation, FDI, growth and energy consumption on emissions (Raihan et al., 2025). From a broader perspective, studies on emissions, energy and sustainability indicate that the use of renewable sources must be interpreted in conjunction with the characteristics of economies and their productive transformations (Umair et al., 2023). Furthermore, energy investment reports enable the transition to be situated within the context of infrastructure and financing decisions that determine its pace (International Energy Agency, 2024). Finally, a review analysis of the integration of the Pacific Alliance highlights that the institutional trajectory of regional blocs provides a distinct context for interpreting the economic integration of their members (Canovas Roque et al., 2025). Taken together, the conceptual framework identifies real GDP and CO_2 emissions as distinct outcomes; trade, FDI, air transport and remittances as channels of international linkage; and renewable energy as a complementary energy dimension. This distinction avoids attributing to a single variable an explanatory role that the literature assigns to multiple mechanisms.

2.7. Formulation of Hypotheses

This study puts forward ten hypotheses to analyse the influence of international trade, FDI, renewable energy consumption, passenger air transport and remittances on economic growth and environmental quality in the member countries of the CAN (Figure 1). These hypotheses are based on empirical evidence that recognises the differentiated effects of economic integration on productive performance and environmental sustainability.

International trade promotes economic growth through market expansion, productive specialisation and greater efficiency in the allocation of resources. Q. H. Nguyen (2024)identifies positive effects of economic globalisation on growth, whilst

Elfaki & Ahmed (2024)highlight its contribution to productivity, innovation and integration into global value chains. Similarly, Ali et al. (2022) demonstrate a positive and significant long-term relationship between globalisation and economic growth in developing countries. These findings suggest that greater trade integration could boost productive activity in the Andean economies. Consequently, the following hypothesis is proposed:

H1. International trade has a positive influence on the economic growth of CAN member countries.

However, trade expansion may also generate environmental externalities associated with increased production, energy consumption and pollutant emissions. Nica et al. (2025) note that trade integration may increase CO_2 emissions in economies with energy-intensive production structures and weak environmental regulations. Similarly, T. P. T. Nguyen et al. (2023) and Kalaycı & Hayaloğlu (2019)identify adverse effects of trade liberalisation and globalisation on environmental quality. This evidence suggests that international trade could exacerbate environmental degradation in CAN countries. Therefore, the following is proposed:

H2. International trade has a negative impact on environmental quality in CAN member countries.

FDI constitutes a mechanism for capital accumulation, technology transfer and the enhancement of productivity. Duong et al. (2022) identify positive effects of FDI and trade liberalisation on economic growth, whilst B. C. X. Nguyen & Ho (2025) highlight its contribution to employment and technology diffusion. Similarly, Banday et al. (2021) demonstrate the economic benefits of FDI in the BRICS countries, and Fazaalloh (2024) acknowledges its contribution to economic performance in activities linked to the mining sector. This evidence supports the argument that foreign

investment flows could promote growth in the Andean economies. Consequently, the following hypothesis is formulated:

H3. Foreign direct investment has a positive influence on the economic growth of CAN member countries.

However, FDI can also generate environmental pressures when it is concentrated in activities that are intensive in energy and natural resources. Christoforidis & Katrakilidis (2022) identify an increase in CO_2 emissions associated with the expansion of investment and production. From the perspective of the 'pollution haven' hypothesis, Christmann & Taylor (2001) and Ochoa-Moreno et al. (2021) examine the relationship between business location decisions and environmental regulations. Similarly, Abdullahi et al. (2023) point out that economies with greater institutional constraints may offer favourable conditions for attracting polluting investment. These arguments lead us to propose:

H4. Foreign direct investment has a negative impact on environmental quality in CAN member countries.

The consumption of renewable energy can stimulate economic growth through energy diversification, a reduction in dependence on conventional fuels and the development of productive infrastructure. Koiry et al. (2026)and Abdi et al. (2025)identify bidirectional relationships between renewable energy consumption and economic growth. Furthermore, Neffati & Khemiri (2025) highlight its contribution to green growth, whilst Hosan et al. (2026) recognise the role of globalisation and financial development in the adoption of clean technologies. This evidence supports the possibility that greater use of renewable energy may contribute to the economic performance of Andean countries. Consequently, the following is proposed:

H5. The consumption of renewable energy has a positive influence on the economic growth of CAN member countries.

From an environmental perspective, renewable energy helps to reduce dependence on fossil fuels and carbon emissions. Koiry et al. (2026), Bilgili et al. (2016) and Petruška et al. (2022)identify negative relationships between renewable energy consumption and CO_2 emissions. These findings are consistent with those of Majewski et al. (2022) and Radmehr et al. (2021), who highlight their contribution to emissions mitigation. Furthermore, Charfeddine & Kahia (2019) identify causal relationships between energy and environmental variables. Consequently, the following is formulated:

H6. The consumption of renewable energy has a negative influence on CO_2 emissions in CAN member countries.

Passenger air transport promotes international connectivity, the mobility of people and the development of economic activities linked to tourism and services. Q. H. Nguyen (2024)identifies a positive effect of air transport on long-term economic growth in South-East Asian countries. Similarly, Law et al. (2022)find a bidirectional causal relationship between passenger air traffic and economic growth, demonstrating that both activities can reinforce one another. These findings suggest that greater air connectivity could boost the Andean economies. Therefore, the following is proposed:

H7. Passenger air transport has a positive influence on economic growth in CAN member countries.

Despite its economic benefits, the expansion of air transport may increase fossil fuel consumption and pollutant emissions. Habib et al. (2022) highlight the environmental pressures associated with aviation. Similarly, Q. H. Nguyen (2024)identifies positive effects of air transport on CO_2 emissions in Southeast Asian

economies, whilst Habib et al. (2022) and Gümüş Akar et al. (2026) find similar results in G20 and BRICS countries, respectively. This evidence suggests that increased air transport activity could deteriorate environmental quality in Andean countries. Consequently, the following hypothesis is proposed:

H8. Passenger air transport has a negative impact on environmental quality in CAN member countries.

Remittances constitute a source of external financing that can stimulate economic growth through consumption, investment and capital formation. Adugna Chomen et al. (2024) identify positive and significant effects of remittances on long-term growth in African countries, whilst Islam et al. (2024) find similar results in middle-income economies. Similarly, Zurita Moreano et al. (2024) demonstrate a favourable contribution of remittances to economic growth and capital formation in Latin American countries, including the four CAN member states. On this basis, the following hypothesis is formulated:

H9. Remittances have a positive influence on economic growth in CAN member countries.

Finally, remittances may influence environmental quality through changes in consumption patterns and households' ability to adopt more efficient technologies. Umair et al. (2023)find that remittances contribute to reducing CO_2 emissions and the ecological footprint in the long term. For their part, Biyase et al. (2024) identify an inverted 'U'-shaped relationship between remittances and emissions, suggesting that, once a certain threshold is exceeded, these funds may promote environmentally sustainable practices. These findings suggest that remittances could help improve the environmental performance of Andean economies. Consequently, the following is proposed:

H10. Remittances have a positive influence on the environmental quality of CAN member countries.

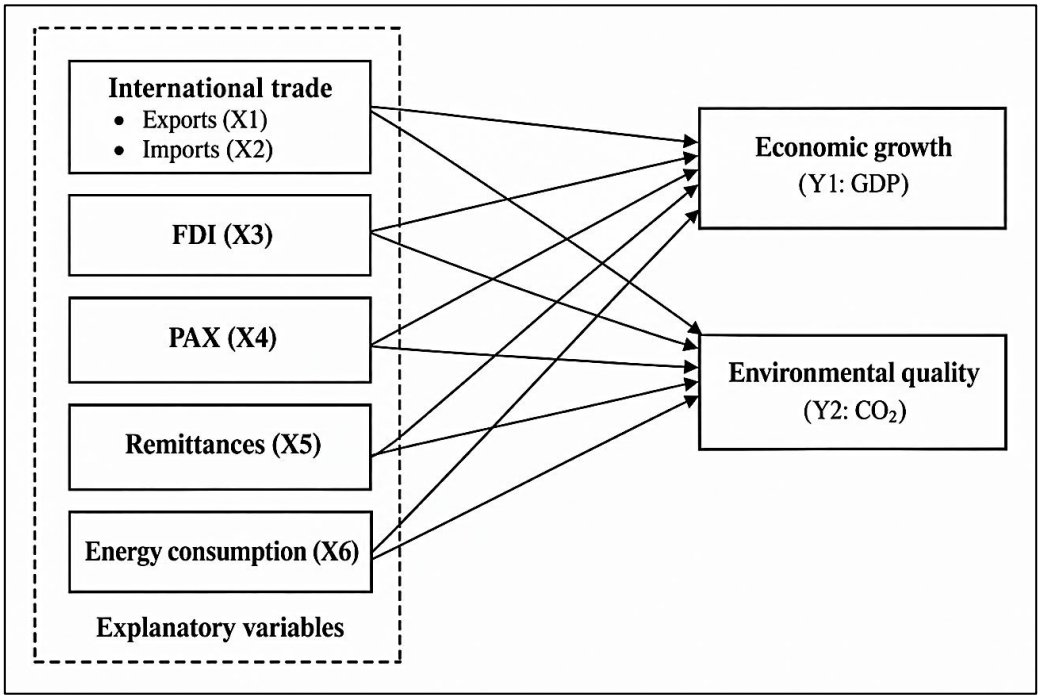


Figure 1. Conceptual model of the study

3. Methodology

3.1. Research design

The research adopts a quantitative approach, with an explanatory scope and a non-experimental longitudinal design. Panel data are used to analyse the influence of various factors associated with economic globalisation on economic growth and environmental quality in CAN countries between 1990 and 2025. This approach is consistent with previous research that uses longitudinal data to examine the relationships between globalisation, economic growth and environmental performance (Gómez Sánchez Torres et al., 2026; Q. H. Nguyen, 2024).

Data and variables

The research utilises secondary data from official international databases (Table 1). The final dataset was organised in a country- -year panel format, with economic growth and environmental quality as dependent variables; these are considered relevant dimensions of economic globalisation and are widely used to analyse its effects on economic and environmental performance (Forte & Costa, 2024; Gómez Sánchez Torres et al., 2026; Q. H. Nguyen, 2024). Furthermore, the independent variables include exports, imports, foreign direct investment, passenger air transport, remittances and energy consumption (Gómez Sánchez Torres et al., 2026; Q. H. Nguyen, 2024; Teixeira et al., 2025).

Variable	Abbreviation	Type of variable	Definition	Unit of measurement	Source	Transformation applied
Real gross domestic product	GDP	Dependent (Model 1)	Represents the total value of goods and services produced by a country over a given period, adjusted for inflation. It reflects the overall level of economic growth.	Constant 2015 US dollars (USD, constant prices)	World Bank	Natural logarithm (ln GDP)
Carbon dioxide emissions	CO_2	Dependent (Model 2)	Refers to the annual total of carbon dioxide emissions from the combustion of fossil fuels and from industry, used as an indicator of environmental quality.	Metric tonnes per year	Our World in Data (OWID)	Natural logarithm (ln CO_2)
Exports and imports (Trade Openness)	EXPO/ IMPORTS	Independent	Measures a country's degree of integration into the global economy, expressed as the sum of exports and imports of goods and services as a	Percentage of GDP (%)	World Bank	Natural logarithm (ln EXPO) (ln IMPO)

			proportion of GDP.			
Foreign direct investment	FDI	Independent	Net foreign direct investment flows as a proportion of GDP, representing the level of integration of international capital.	Percentage of GDP (%)	World Bank	Inverse hyperbolic sine asinh(FDI)
Passenger air transport	PAX	Independent	Represents the total annual number of passengers carried by airlines registered in the country, on domestic and international flights, regardless of the passengers' origin or destination	Number of passengers carried per year	World Bank	Natural logarithm (In PAX)
Personal remittances received	REM	Independent	This refers to personal remittances received from abroad by resident households, in cash or in kind, and remuneration of resident employees received from non-resident employers, expressed as a proportion of GDP.	Percentage of GDP (%)	World Bank	Natural logarithm (In REM)
Renewable Energy	ENERGY	Independent	Represents the proportion of renewable energy consumption relative to total final energy consumption in countries over a given period.	Percentage of total final energy consumption (%)	World Bank	Natural logarithm (In ENERGY)

Error term	ε	Stochastic component	Captures un d factors that influence the dependent variable but are not explicitly included in the model.	—	—	—
Country	j	Cross-sectional index	Represents each member country of the CAN (Bolivia, Colombia, Ecuador and Peru)	—	—	—
Year	t	Time index	Represents the time dimension of the 1990–2025 panel data set.	—	—	—

Table 1. Definition and measurement of the variables used in the econometric models.

In order to minimise problems arising from the scale of measurement and to enable the coefficients to be interpreted in relative terms, the positive variables were transformed using natural logarithms (ln). In the case of FDI, due to the presence of negative values in certain years, the inverse hyperbolic sine transformation, asinh(FDI), was applied instead of (ln). This transformation allows negative observations to be retained whilst, at the same time, behaving approximately like a logarithm for high absolute values. Thus, the variables used in the estimates were (ln GDP), (ln CO2), (ln EXP), (ln IMP), (asinh(FDI)), (ln PAX), (ln REM) and (ln ENERGY).

3.2. Specification and econometric equations

Following the methodological approach employed by Q. H. Nguyen (2024), two models were estimated and fitted to identify the effect of factors linked to economic globalisation on economic and environmental performance.

Model 1 takes GDP growth as the dependent variable:

$$\ln GDP_{jt} = \beta_1 \ln EXP_{jt} + \beta_2 \ln IMP_{jt} + \beta_3 asinh(FDI_{jt}) + \beta_4 \ln PAX_{jt} + \beta_5 \ln REM_{jt} + \beta_6 \ln ENERGY_{jt} + \varepsilon_{jt} \quad (1)$$

Meanwhile, Model 2 uses CO_2 emissions as the dependent variable:

$$\ln CO_{2,jt} = \beta_1 \ln EXP_{jt} + \beta_2 \ln IMP_{jt} + \beta_3 asinh(FDI_{jt}) + \beta_4 \ln PAX_{jt} + \beta_5 \ln REM_{jt} + \beta_6 \ln ENERGY_{jt} + \varepsilon_{jt} \quad (2)$$

where *j* represents each Andean country and *t* corresponds to the year of observation. The parametersβ represent the effects associated with each explanatory variable, whilstε_{jt} corresponds to the error term.

Before estimating both models, following Q. H. Nguyen (2024), the IPS test developed by Im et al. (2003)was used. The results obtained subsequently enabled us to determine the most appropriate econometric method for the estimation.

Data handling and processing

The processing, transformation and econometric analysis of the data were carried out using the statistical software Jamovi 2.7 via Rj Editor and R 4.5 (R Core Team, 2025; The Jamovi Project, 2025). The stationarity of the time series was assessed using the panel unit root test by Im et al. (2003), considering specifications with an intercept and with an intercept and trend. This strategy follows Q. H. Nguyen (2024), who uses IPS to determine the order of integration before selecting the Panel ARDL model.

Given that the results showed a combination of variables that were stationary at level, I(0), and at first difference, I(1), with no evidence of second-order integrated variables, I(2), the Panel ARDL estimation was carried out using the PMG method. This estimator imposes homogeneity on the long-run coefficients whilst allowing for heterogeneity in short-run dynamics across countries. Following the strategy of Q. H. Nguyen (2024), up to four lags and various deterministic specifications were evaluated. The final selection prioritised models with a negative, statistically significant error

correction term (COINTEQ01) falling between −1 and 0 and, amongst the admissible specifications, the Akaike Information Criterion (AIC).

Finally, certain observations not available in the original sources were imputed using estimation procedures. The technique employed was selected according to the temporal availability of each time series and applied individually for each country; examples include linear regression of the variable against time—equivalent to the FORECAST.LINEAR function—and moving averages in Microsoft Excel 365 spreadsheets. These estimates were made solely for the purpose of completing the time series structure of the panel and maintaining a homogeneous time series for Bolivia, Colombia, Ecuador and Peru. Subsequently, the observed and estimated data were integrated into a single database in Microsoft Excel 365 and subjected to the same transformation procedure (ln) and econometric analysis.

4. Results

4.1. Descriptive statistics

The sample comprised Bolivia, Colombia, Ecuador and Peru for the period 1990–2025, with 36 annual observations per country and 144 observations in total. The descriptive statistics reveal considerable heterogeneity amongst the variables analysed. Significant differences were observed in the levels of trade, foreign direct investment, air transport, remittances and energy consumption. In particular, FDI showed negative values in certain observations, which justified its transformation using the inverse hyperbolic sine function (Table 2).

Variable	Mean	Median	Maximum	Minimum	Standard deviation	Observations
GDP	1.1619×10^{11}	9.2951×10^{10}	3.6730×10^{11}	1.1974×10^{10}	9.1639×10^{10}	144
CO_2	3.9900×10^{7}	3.3144×10^{7}	1.0373×10^{8}	8.4423×10^{6}	2.4404×10^{7}	144
EXP	23.4192	21.6489	47.1662	12.2024	7.9609	144
IMP	24.5024	23.8544	41.9714	13.7725	5.5031	144

FDI	2.7818	2.4396	12.1966	−2.6693	2.3431	144
PAX	7.6707×10^{6}	4.2649×10^{6}	4.2399×10^{7}	752,300	9.1010×10^{6}	144
REM	2.3826	1.9476	8.0439	0.0636	1.6741	144
ENERGY	26.2958	28.7500	41.2000	11.8000	8.2682	144

Table 2. Descriptive statistics

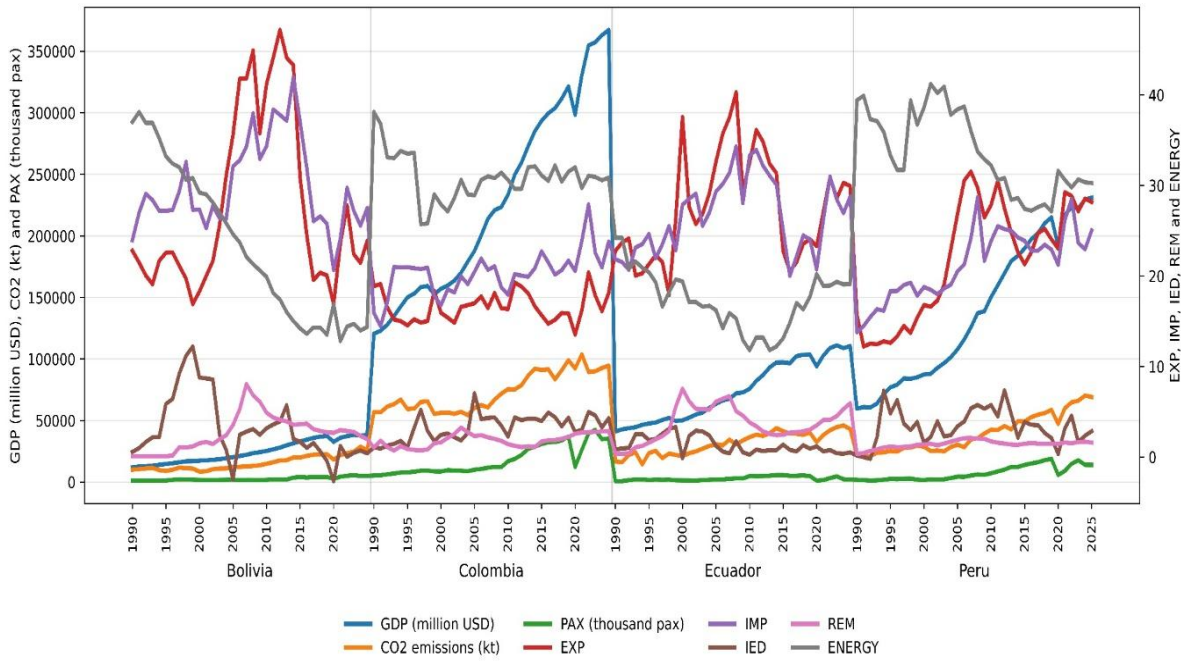


Figure 2. Trends in the study variables. *Note:* The left-hand axis corresponds to GDP, CO_2 and PAX, whilst the right-hand axis corresponds to EXP, IMP, FDI, REM and ENERGY.

Figure 2 shows the temporal trends of the analysed variables for Bolivia, Colombia, Ecuador and Peru over the period 1990–2025. In general, there is marked heterogeneity between the countries, both in terms of the magnitude and the trajectory of the time series.

GDP shows a more pronounced upward trend in Colombia and Peru, whilst Bolivia and Ecuador exhibit relatively lower levels. Similarly, CO_2 emissions tend to increase over time, albeit at different rates across countries. Furthermore, variables linked to foreign trade, particularly exports and imports, exhibit significant fluctuations, suggesting differentiated external dynamics within the CAN. Meanwhile, FDI, remittances, passenger air transport and energy consumption also show divergent trajectories, reinforcing the existence of structural heterogeneity in the panel.

4.2. IPS unit root tests

Following the procedure employed by Q. H. Nguyen (2024), the stationarity of the time series was initially assessed. The results indicate a combination of I(0) and I(1) series (Table 3). Specifically, lnIMP, asinh(FDI) and lnREM were stationary at the level, whilst lnGDP, $lnCO_2$, lnEXP, lnPAX and lnENERGY became stationary after the first difference. None of the variables showed evidence of I(2) integration. This combination satisfies the condition for the applicability of the ARDL panel approach, as also used by Q. H. Nguyen (2024).

Variable	Intercept	Intercept + trend	1st difference: intercept	1st difference: intercept + trend	Order
lnGDP	1.156	1.803	−9.876***	−9.396***	I(1)
$lnCO_2$	1.965	−0.555	−14.203***	−13.084***	I(1)
lnEXP	−2.079**	−0.717	−9.289***	−8.519***	I(1)
lnIMP	−2.217**	−2.201**	−10,560***	−9.600***	I(0)
asinh(FDI)	−3.916***	−4,532***	−11,301***	−11.051***	I(0)
lnPAX	0.533	−1.703**	−10.186***	−9.456***	I(1)
lnREM	−4.154***	−1,877**	−6.797***	−6.631***	I(0)
lnENERGY	−1.533*	0.002	−8.614***	−8.467***	I(1)

Table 3. IPS unit root tests. *Note:* *, ** and *** indicate statistical significance at the 10 per cent, 5 per cent and 1 per cent levels, respectively.

Model 1: Economic growth

Table 4 presents the results of Model 1 with ln(GDP) as the dependent variable. The selected specification included one lag and no deterministic component, yielding an AIC of −4.6583.

Component	Variable	Coefficient	Standard error	p-value
Long term	lnEXP	29.7737	307.4558	0.923
	lnIMP	53.9099	543.7544	0.921
	asinh(FDI)	20.6146	218.6885	0.925
	lnPAX	−16.1760	175.7566	0.927
	lnREM	0.2999	8.1908	0.971
	lnENERGY	15.7578	139.8172	0.910
Short term	COINTEQ01	−0.000426***	0.000067	0.008
	ΔlnEXP	−0.0110	0.0145	0.505
	ΔlnIMP	0.1179***	0.0082	<0.001
	Δasinh(FDI)	0.0112**	0.0032	0.041

	ΔlnPAX	0.0546***	0.0091	0.009
	ΔlnREM	−0.0157	0.0162	0.406
	ΔlnENERGY	−0.0747	0.0554	0.271
Model statistic	**Value**			
S.E. of regression	0.020251			
Sum of squared residuals	0.045930			
Log-likelihood	364.0778			
Akaike information criterion	−4.6583			
Bayesian information criterion	−3.8598			

Table 4. PMG-ARDL estimation of Model 1. *Note*. Dependent variable: lnGDP. *, ** and *** denote significance at 10 per cent, 5 per cent and 1 per cent, respectively.

In the long run, none of the six factors had a statistically significant coefficient. Consequently, the estimation does not provide sufficient statistical evidence to attribute an individual long-run effect of EXP, IMP, FDI, PAX, REM or ENERGY on GDP, holding all other factors constant.

In contrast, statistically significant relationships are identified in the short run. Imports have a positive coefficient of 0.1179 ($p < 0.01$), whilst passenger air transport has a coefficient of 0.0546 ($p < 0.01$). As both variables are expressed in logarithms, these results indicate that, with *all other factors held constant*, a 1 per cent increase in IMP is associated with an approximate 0.118 per cent rise in GDP in the short term, whilst a 1 per cent increase in PAX is associated with an approximate 0.055 per cent rise in GDP.

The transformation of FDI also shows a positive and significant effect$(\beta = 0.0112;\ p = 0.041)$; however, as it is expressed as$asinh(IED)$, its coefficient should not be interpreted directly as a conventional percentage elasticity.

The error correction term is negative and significant$(\mathrm{COINTEQ01} = -0.000426;\ p = 0.008)$, indicating the existence of a mechanism for a return to equilibrium following short-term disturbances. However, its magnitude suggests a slow rate of adjustment, equivalent to approximately 0.043 per cent of the imbalance per period.

Country-specific results reveal heterogeneity in the short-run relationships. Imports have a positive and significant effect on economic growth in all four countries, with coefficients of 0.1031 in Bolivia, 0.1097 in Colombia, 0.1407 in Ecuador and 0.1180 in Peru (Table 5).

Variable	Bolivia	Colombia	Ecuador	Peru
COINTEQ01	−0.0003***	−0.0006***	−0.0004***	−0.0004***
ΔlnEXP	−0.0266	−0.0309	−0.0181	0.0318
ΔlnIMP	0.1031**	0.1097***	0.1407***	0.1180**
Δasinh(FDI)	0.0094**	0.0096	0.0053	0.0204***
ΔlnPAX	0.0445*	0.0815***	0.0430***	0.0494***
ΔlnREM	−0.0059	−0.0135	−0.0603***	0.0170
ΔlnENERGY	−0.1883***	0.0187	0.0223	−0.1513**

Table 5. Cross-section of Model 1. *Note*. Dependent variable: ΔlnGDP. *, ** and *** indicate statistical significance at the 10 per cent, 5 per cent and 1 per cent levels, respectively.

Similarly, PAX exhibits positive coefficients across all four countries, although the significance is weaker in Bolivia. Transformed FDI has a positive and significant effect, particularly in Bolivia and Peru. Remittances, meanwhile, show a negative and significant coefficient only in Ecuador, whilst ENERGY exhibits a negative and significant relationship in Bolivia and Peru. The four COINTEQ01 terms are negative and statistically significant, indicating a process of correcting the imbalance in each country, albeit at a slow pace.

Model 2: CO_2 emissions

The results of Model 2 show statistically significant effects in both the long and short term. In the long term, PAX has a positive and significant effect on CO_2 emissions($\beta = 0.3630;\ p < 0.001$) . For this model, a one-lag specification with a constant was selected, with an AIC of −1.7702 (Table 6).

In terms of elasticity, a 1 per cent increase in air passenger transport is associated with an approximate 0.363 per cent increase in CO_2 emissions, holding all other factors constant.

Component	Variable	Coefficient	Standard error	p-value
Long term	lnEXP	0.2283	0.1754	0.193
	lnIMP	−0.0946	0.3664	0.796
	asinh(FDI)	−0.0309	0.0351	0.378
	lnPAX	0.3630***	0.0559	<0.001
	lnREM	−0.0502	0.0345	0.145
	lnENERGY	−0.5757***	0.1657	<0.001
Short term	COINTEQ01	−0.2928**	0.0798	0.035
	ΔlnEXP	−0.0502	0.0989	0.647
	ΔlnIMP	0.1145	0.0651	0.177
	Δasinh(FDI)	0.0022	0.0122	0.867
	ΔlnPAX	0.1452***	0.0134	0.002
	ΔlnREM	0.0179	0.0173	0.377
	ΔlnENERGY	−0.2044*	0.0734	0.069
	Constant	3.8400**	0.9580	0.028
Model statistic	**Value**			
S.E. of regression	0.100163			
Sum of squared residuals	1.083525			
Log-likelihood	165.9128			
Akaike information criterion	−1.7702			
Bayesian information criterion	0.8877			

Table 6. PMG-ARDL estimation of Model 2. *Note*. Dependent variable: $lnCO_2$. *, ** and *** denote significance at 10 per cent, 5 per cent and 1 per cent, respectively.

In contrast, ENERGY has a negative coefficient of $-0.5757 (p < 0.001)$. Thus, a 1 per cent increase in ENERGY is associated with an approximate 0.576 per cent reduction in CO_2 emissions in the long run. The specific economic interpretation of this result suggests that a 1 per cent increase in renewable energy is associated with a reduction in CO_2 in the long term. Meanwhile, EXP, IMP, FDI and REM did not reach statistical significance in the long term.

In the short term, PAX maintains a positive and significant effect$(\beta = 0.1452;\ p = 0.002)$, such that a 1 per cent increase is associated with approximately 0.145 per cent more CO_2 emissions. ENERGY retains a negative coefficient$(\beta = -0.2044)$, although its significance is only reached at the 10 per cent level. COINTEQ01 has a value of −0.2928 and is significant at the 5 per cent level. This

implies that approximately 29.3 per cent of the deviation from the long-run equilibrium is corrected during the subsequent period, providing evidence of the model's dynamic convergence.

The breakdown by country shows that PAX is the variable with the most consistent behaviour, exhibiting a positive association with CO_2 emissions in all four countries. The coefficient is significant at the 10 per cent level in Bolivia and Ecuador, and at the 5 per cent level in Colombia and Peru (Table 7).

Variable	**Bolivia**	**Colombia**	**Ecuador**	**Peru**
COINTEQ01	−0.5302***	−0.1862*	−0.2204	−0.2346**
ΔlnEXP	−0.1076	−0.2514*	−0.0628	0.2209
ΔlnIMP	0.2136	0.2176	0.0841	−0.0572
Δasinh(FDI)	0.0051	−0.0034	−0.0259	0.0329
ΔlnPAX	0.1778*	0.1178**	0.1557*	0.1296**
ΔlnREM	−0.0244	0.0166	0.0602	0.0192
ΔlnENERGY	−0.2898	−0.3333*	−0.0032	−0.1913
Constant	6.6894***	2.5726*	2.9149	3.1832**

Table 7. Cross-section of Model 2. *Note*. Dependent variable: $\Delta \ln CO_2$. *, ** and *** indicate statistical significance at the 10 per cent, 5 per cent and 1 per cent levels, respectively.

There are significant differences in the rate of error correction. Bolivia has the fastest rate of adjustment, with a COINTEQ01 of −0.5302, representing approximately 53.0 per cent correction of the imbalance per period. Peru records approximately 23.5 per cent, whilst Colombia shows an adjustment of 18.6 per cent, although this is significant only at the 10 per cent level. For Ecuador, whilst the sign of the COINTEQ01 is as expected, the coefficient is not statistically significant.

Meanwhile, EXP shows a negative and marginally significant relationship only in Colombia, whilst ENERGY also exhibits a negative effect that is significant at the 10

per cent level in that country. For IMP, FDI and REM, no statistically significant short-term effects are identified at the national level.

Overall, the findings reveal differences between the determinants of economic growth and CO_2 emissions across the CAN countries. For economic growth, the main effects are concentrated in the short term, particularly through imports, air travel and, to a lesser extent, FDI. By contrast, no statistically significant individual coefficients are identified in the long-term equation.

A more defined structure is observed for CO_2 emissions. Passenger air transport shows a positive association in both the short and long term, whilst ENERGY maintains a negative association, particularly in the long term. Furthermore, the negative and significant COINTEQ01 of the aggregate model confirms a process of convergence towards equilibrium, with an approximate correction of 29.3 per cent per period. The heterogeneity of the country-specific coefficients further supports the use of a PMG estimator that combines common long-run relationships with heterogeneous short-run adjustments.

5. Discussion

The results of this study provide evidence of the differentiated relationships between the channels of economic globalisation, economic growth and environmental quality in the CAN countries. Unlike approaches that treat international integration as a homogeneous process, the findings show that its various mechanisms do not exhibit equivalent associations with economic and environmental performance. This interpretation is consistent with evidence recognising the heterogeneity of globalisation's effects depending on productive characteristics and levels of economic development (Lv & Xu, 2018). In Latin America and the Caribbean, the relationships between openness, economic freedom and growth have also shown differences across countries and

dimensions of integration (Santiago et al., 2020). From an environmental perspective, the evidence for South Asian economies highlights that the economic expansion associated with globalisation can coexist with increased pressures on the environment (Kiani et al., 2021). Similarly, the results for countries in the Pacific Alliance suggest that the links between globalisation, growth and emissions must be interpreted in light of regional economic characteristics (Gómez Sánchez Torres et al., 2026). In this regard, the results obtained extend the approach applied by Q. H. Nguyen (2024)to Andean economies and reveal that factors related to productive expansion do not necessarily coincide with those associated with carbon emissions. However, this differentiation should be understood as evidence of econometric associations, without automatically attributing causal relationships to the estimated coefficients.

Regarding economic growth, the model identifies positive and statistically significant short-term associations for imports ($\beta = 0.1179$; $p < 0.001$), FDI ($\beta = 0.0112$; $p = 0.041$) and passenger air transport ($\beta = 0.0546$; $p = 0.009$). In contrast, exports, remittances and renewable energy consumption do not exhibit statistically significant coefficients in the aggregate short-run estimation, whilst none of the explanatory variables achieves individual significance in the long run. These results suggest that the mechanisms of international integration are related to output in a selective and predominantly contemporaneous or immediate manner, rather than establishing persistent individual associations over the analytical horizon. The positive relationship with imports is consistent with the argument that the diversification of external inputs can expand productive possibilities and contribute to growth (Yu & Meng, 2023). Furthermore, evidence for middle-income economies recognises that trade and FDI can enhance economic performance through productivity and the incorporation of productive resources (Duong et al., 2022). However, the lack of significance of exports

suggests that not all components of trade have the same relationship with output, thereby qualifying the growth expectations associated with greater economic openness (Banday et al., 2021). This finding is also consistent with research highlighting the importance of domestic conditions when assessing the effects of openness on growth (Prawoto & Nurhanifah, 2025). Consequently, hypothesis H1 is partially supported, focusing on imports and the short term, with insufficient evidence to affirm a general positive relationship between international trade and long-term economic growth.

The positive short-term relationship between FDI and output constitutes a second relevant finding, although its interpretation requires consideration of the heterogeneity among Andean countries. The disaggregated estimate shows positive and significant associations in Bolivia and Peru, whilst Colombia and Ecuador do not present equivalent statistical evidence. These differences suggest that the economic contribution of foreign capital may be conditioned by the productive capacity and sectoral characteristics of each economy. Evidence from African countries recognises that foreign investment can contribute to growth, although the results vary according to national economic conditions (Chibalamula et al., 2023). Furthermore, sectoral analyses show that the benefits of FDI can vary across sectors and host regions (Fazaalloh, 2024). From an institutional perspective, the quality of institutions can influence countries' ability to transform foreign investment into economic growth (B. C. X. Nguyen & Ho, 2025). This interpretation is also consistent with research identifying economic freedom as a key determinant in the relationship between investment and productive performance (Shokhrukh et al., 2023). Therefore, the results provide partial support for H3, identifying a favourable short-term relationship without confirming a statistically significant individual effect in the long term. In analytical terms, this evidence suggests that the inflow of international capital should not be regarded as a

guarantee of sustained growth, particularly when its contribution may vary across economies with different productive structures.

Passenger air transport is the sector that shows the most consistent association with both dimensions of the study. About economic growth, its aggregate coefficient is positive and significant in the short term, whilst the individual estimates show positive relationships in all four CAN countries, albeit to varying degrees. This pattern is consistent with the role of air connectivity in the movement of people and the development of activities related to tourism, services and business interaction. The evidence on air transport and growth recognises that connectivity can contribute to economic performance, although this relationship depends on market characteristics and the available infrastructure (C. Van Nguyen, 2024). However, the economic association identified does not translate into a favourable environmental outcome. In the emissions model, air transport exhibits positive and significant coefficients in both the long run ($\beta = 0.3630$; $p < 0.001$) and the short run ($\beta = 0.1452$; $p = 0.002$). These findings are consistent with evidence identifying environmental pressures arising from the intensity of air transport in G20 economies (Habib et al., 2022). Furthermore, recent studies on BRICS countries document relationships between aviation activity and emissions, although the magnitude of these relationships may vary across economies (Gümüş Akar et al., 2026). Specific research on air transport and emissions in the G20 also reinforces the relevance of this sector for understanding the relationship between connectivity and pollution (Gül, 2025). Consequently, the results support H7 exclusively in the short term and H8 across both time horizons, highlighting a tension between the economic benefits associated with connectivity and its environmental pressures.

Conversely, renewable energy consumption shows a negative and statistically significant relationship with CO_2 emissions in the long term ($\beta = -0.5757$; $p < 0.001$),

whilst its short-term coefficient is also negative, although significant only at the 10 per cent level ($\beta = -0.2044$; $p = 0.069$). This result constitutes one of the main environmental findings of the research, as it suggests that greater use of renewable sources is associated with a reduction in emissions in Andean economies. International evidence recognises that renewable energy can contribute to improving ecological sustainability through reduced dependence on carbon-intensive sources (Abdi et al., 2025). Furthermore, studies on globalisation, financial development and renewable energy identify that these dimensions can collectively help to explain differences in environmental performance (Hosan et al., 2026). However, the relationship between renewable energy and growth does not necessarily exhibit the same direction or significance across all time horizons, due to the productive and financial adjustments associated with the energy transition (Koiry et al., 2026). This heterogeneity is also consistent with evidence regarding the asymmetric effects of globalisation and renewable energy consumption on environmental sustainability (Tran, 2024). Furthermore, research on green growth highlights that the outcomes of the energy transition may depend on institutional quality and national economic capacities (Neffati & Khemiri, 2025). In the case of the CAN, renewable energy consumption does not show a statistically significant association with GDP in the aggregate model; therefore, H5 does not receive sufficient empirical support. In contrast, H6 is supported by the environmental model, particularly in the long term. This difference suggests that the favourable environmental effects of renewable energy may manifest themselves without there necessarily being a positive and statistically identifiable relationship with the level of production during the period analysed.

In contrast, the results relating to exports, FDI and remittances do not provide sufficient statistical evidence to establish individual associations with CO_2 emissions in

the short- or long-term aggregate models. The lack of statistical significance does not prove that these factors have no environmental effects, but rather that their relationships could not be statistically distinguished from zero under the specifications used. In the case of exports, this result qualifies the arguments that trade expansion necessarily increases emissions through greater energy-intensive production. Evidence from Latin America indicates that the relationship between trade, foreign investment and pollution may depend on economic specialisation and the spatial characteristics of productive activities (Mahmood, 2023). Furthermore, research on North American economies suggests that the environmental effects of globalisation must be examined by considering the specific economic conditions of each country (Kalaycı & Hayaloğlu, 2019). With regard to FDI, the lack of environmental significance also prevents us from confirming the predominance of a 'refuge effect' or a 'pollution halo'. International evidence shows that the relationship between foreign capital and emissions may change as the level of development of host economies increases (Kim & Seok, 2023). Complementarily, studies on Latin America identify heterogeneous relationships between FDI and environmental quality, suggesting that the results depend on economic characteristics that may differ across countries (Ochoa-Moreno et al., 2021). Furthermore, the literature on pollution havens recognises the importance of regulatory and productive conditions in the environmental behaviour of foreign capital (Christoforidis & Katrakilidis, 2022). Consequently, H2 and H4 do not receive sufficient empirical support in the aggregate estimation. These results reinforce the need to distinguish between theoretically plausible mechanisms and relationships that are supported by statistical evidence in the context under study.

Remittances also deviate from theoretical expectations. Although the literature recognises their potential to stimulate consumption, investment and capital formation,

the aggregate models do not identify statistically significant coefficients for either GDP or CO_2 emissions. The evidence for middle-income economies identifies potentially favourable contributions from remittances to growth but acknowledges that these outcomes may depend on domestic economic conditions (Islam et al., 2024). Furthermore, research from Latin America highlights the relationship between remittances, capital formation and structural transformation, although these associations are not necessarily equivalent across countries (Zurita Moreano et al., 2024). From a dynamic perspective, it has been documented that the effect of remittances on growth can vary between the short and long term (Adugna Chomen et al., 2024). Their environmental impact presents an additional layer of complexity, as the funds received can alter both the demand for energy-intensive goods and households' ability to adopt more efficient technologies. Evidence from southern Africa identifies a non-linear relationship between remittances and emissions, which calls into question the existence of a uniform environmental pattern (Biyase et al., 2024). Furthermore, studies on large recipient economies show that remittances may be associated with lower emissions and a smaller ecological footprint under certain conditions (Umair et al., 2023). Within the Andean Community (CAN), only Ecuador shows a significant negative relationship between remittances and growth in the short term, a result that suggests national heterogeneity not reflected in the aggregate estimate. Therefore, H9 and H10 do not receive sufficient statistical support. These findings indicate that the existence of international income transfers does not automatically imply productive or environmental improvements without considering the mechanisms through which they are utilised.

A comparison of the two models reveals further differences in their long-term adjustment mechanisms. In the economic growth model, the error correction term is

negative and statistically significant, but its magnitude is extremely small (−0.000426), equivalent to an approximate correction of 0.043 per cent of the imbalance per period. This result indicates a very slow estimated convergence, which should be interpreted with caution, particularly as none of the individual long-run coefficients is statistically significant. In contrast, the environmental model has an error correction term of −0.2928, which is significant at the 5 per cent level, implying an approximate correction of 29.3 per cent of the imbalance over the following period. The national breakdown reveals further differences: Bolivia exhibits the fastest rate of environmental adjustment, followed by Peru and Colombia, whilst in Ecuador the coefficient does not reach statistical significance. These differences are consistent with evidence highlighting the heterogeneity of the relationships between globalisation and sustainability in panel models (Lv & Xu, 2018). Furthermore, research on countries with different levels of sustainability recognises that economic and environmental performance can follow distinct trajectories (Teixeira et al., 2025). Analyses of institutional quality also suggest that national conditions can influence the relationships between economic activity and environmental performance (Mohamed et al., 2025). In Latin America, evidence of the differentiated economic effects of globalisation reinforces the need to avoid generalisations across economies with distinct characteristics (Santiago et al., 2020). Finally, the approach developed by Q. H. Nguyen (2024)provides a methodological framework for jointly examining the channels of international integration and their short- and long-term relationships. However, the virtually zero adjustment speed of the growth model and the imprecision of its long-term coefficients require further assessment of its stability before attributing a structural economic interpretation to it.

Overall, the results suggest that the relationships between economic globalisation, growth and environmental quality in the CAN countries are selective and

depend both on the integration channel and the time horizon considered. Imports, FDI and air travel show positive associations with growth in the short term, whilst air transport is the main international integration variable associated with higher emissions across both time horizons. In contrast, renewable energy consumption shows a negative association with emissions, particularly in the long term, whilst not exhibiting a statistically significant positive relationship with aggregate GDP. This distinction allows for a more nuanced interpretation of views that regard globalisation as a mechanism that is automatically favourable or detrimental to sustainability. Evidence on the relationship between trade, investment and emissions in Latin America highlights that environmental outcomes are determined by specific productive and structural factors (Mahmood, 2023). Furthermore, studies on the energy transition suggest that the integration of renewable energy sources can alter the environmental pressures associated with economic expansion (Abdi et al., 2025). The literature on air connectivity confirms the importance of considering the environmental costs of international travel (Gümüş Akar et al., 2026), whilst evidence on remittances shows that cross-border financial flows do not have uniform consequences for the environment either (Biyase et al., 2024). Consequently, the main empirical contribution of this research is to demonstrate that channels of international integration exhibit differentiated economic and environmental associations in the Andean context. From a public policy perspective, the results suggest the advisability of complementing economic integration strategies with measures to promote energy efficiency, technological modernisation and emissions reduction in sectors linked to international connectivity. However, these implications should be regarded as indicative, given that the observational design does not allow for the establishment of causal effects or the direct assessment of the effectiveness of specific policy instruments.

6. Conclusions, recommendations and future research

6.1. Conclusions

This study analysed the relationship between the main channels of economic globalisation, renewable energy consumption, economic growth and environmental quality in Bolivia, Colombia, Ecuador and Peru during the period 1990–2025. Using two ARDL panel models estimated using the Pooled Mean Group (PMG) approach, the results show that international economic integration does not exhibit uniform associations with the productive and environmental performance of the CAN countries. On the contrary, these relationships depend on the channel under consideration, the time horizon and national economic characteristics, thereby challenging interpretations that attribute uniform benefits or costs to globalisation.

About economic growth, imports, FDI and passenger air transport show positive and statistically significant associations in the short run. However, none of the explanatory variables achieves individual significance in the long run, which prevents the establishment of persistent relationships under the estimated specification. The national disaggregation also reveals differences in the magnitude and significance of the coefficients, particularly for FDI and renewable energy consumption. These findings suggest that the mechanisms of international integration may be linked to immediate economic expansion without necessarily guaranteeing sustained growth trajectories.

Regarding environmental quality, the results show clearer relationships. Passenger air transport exhibits a positive and significant association with CO_2 emissions in both the short and long term, highlighting a tension between international connectivity and sustainability. In contrast, renewable energy consumption maintains a negative and significant relationship with emissions in the long term, which supports its importance in reducing environmental pressures. Exports, imports, FDI and remittances

do not show statistically significant environmental associations in the aggregate models; therefore, it is not possible to confirm the pollution or mitigation mechanisms proposed for these variables.

The main contribution of the study is to demonstrate that the economic and environmental associations of globalisation can diverge within the same regional area. In particular, air connectivity is associated with higher levels of economic activity and emissions, whilst renewable energy shows a favourable environmental association without a statistically identifiable contribution to aggregate GDP. These results reinforce the need to analyse growth and sustainability jointly, distinguishing between channels of integration and avoiding the view of globalisation as a process with automatic effects.

6.2. Recommendations

From an economic policy perspective, the results suggest that CAN countries should complement their international integration strategies with policies aimed at strengthening productive capacities, energy efficiency and environmental sustainability. The positive association between imports and short-term growth highlights the desirability of facilitating access to intermediate goods, technologies and productive equipment, ensuring that their incorporation contributes to sustained improvements in productivity and competitiveness.

It is also important to strengthen institutional mechanisms that foster greater coordination between FDI and national productive development. This involves promoting business value chains, technology transfer and environmental standards that enable foreign capital to be utilised effectively, without if its inflow automatically generates economic or environmental benefits.

On environmental matters, the findings justify paying particular attention to energy efficiency in air transport and the expansion of renewable energy sources. It is recommended to drive forward the technological modernisation of the aviation sector, promote investment in sustainable energy infrastructure and strengthen regional coordination on energy transition. These measures constitute policy guidelines consistent with the findings, although their effectiveness requires specific evaluations.

6.3. Limitations and future research

The study has limitations that must be considered when interpreting its findings. Firstly, the panel comprises four countries and 144 annual observations, which limits the ability to generalise and may affect the accuracy of the dynamic estimates. Secondly, the use of CO_2 emissions as an indicator of environmental quality does not consider other dimensions, such as local air pollution, biodiversity or the ecological footprint. Thirdly, the observational design allows statistical associations to be identified but does not enable conclusive causal relationships to be established. Furthermore, the use of estimated values to complete certain observations and the slow rate at which errors in the economic y model are corrected suggest that its long-term relationships should be interpreted with caution.

Future research could extend the analysis to other Latin American blocs, incorporate multidimensional environmental indicators and examine sectoral differences in trade and foreign investment. It would also be relevant to assess non-linear relationships, possible asymmetries and interaction effects between globalisation, institutional quality and the energy transition. Finally, it is recommended that the results be tested using alternative estimators, cross-sectional dependence tests, sensitivity analyses and specifications that address potential endogeneity. These extensions would contribute to a more precise understanding of the conditions under which international

economic integration can foster growth that is compatible with environmental sustainability in Latin America.

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