Determinants of the Energy Transition in Latin America

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ABSTRACT
This study investigated the energy transition in 17 Latin American countries during the period 2000–2021, addressing its theoretical foundations, the evolution of its determining variables, and the factors that drive or hinder it. The descriptive analysis reveals a deeply heterogeneous region. The evolution of key economic indicators, such as GDP per capita, investment, and natural resource rents, shows strong procyclicality and vulnerability to global cycles, affecting the capacity for sustainable investment. To identify the determinants, a panel data model was implemented, whose final specification was a random-effects model after passing the Hausman test. The results of the econometric analysis identify economic growth (GDP per capita) and Foreign Direct Investment (FDI) as the main catalysts of the transition, showing a positive and significant relationship with renewable energy consumption. However, the model also reveals significant structural barriers: high CO_2 emissions, greater domestic credit to banks (CIB), and, crucially, Gross Fixed Capital Formation (GFCF) have a negative impact. This suggests that investment in the region is still predominantly directed toward non-sustainable sectors. Variables such as urbanization or natural resource rents were not found to be significant, reinforcing the conclusion that the transition depends more on structural economic factors and the direction of investment than on demographic trends or resource endowments.

Introducción

The energy transition toward renewable sources has shown significant progress and is a critical element in promoting sustainability; however, the substantial consumption of fossil fuels remains a constant (Najm & Matsumoto, 2020; Tian et al., 2022). The structural change required to create a new energy system will demand multiple actions and will take a considerable amount of time to materialize; nevertheless, new technologies, which are less dependent on fossil fuels, will promote this new dynamic (Shojaeddini et al., 2019). Due to its multidisciplinary nature, the definition of energy transition can encompass various perspectives involving different stakeholders and elements of interest, ranging from the local to the global level, including regulation, distribution, and trade, among others (Johnstone & McLeish, 2020). The effects of climate change have negatively affected health and have intensified the need to replace fossil fuels. They have also accelerated actions leading to a far-reaching energy transition through collaboration aimed at achieving the required innovations. This scenario demonstrates that the initial investments required for its development may be excessively high (Kumar et al., 2021).

Although multiple perspectives on energy transition exist, the main idea is to shift the current system toward other energy sources or alternative production technologies (Sanz, 2024). Transitioning from traditional economic systems toward sustainable development involves socio-technical transformations that explain how sustainability transitions are carried out (Wagner & Matuszek, 2022). These transitions may encompass different dimensions, ranging from technical, institutional, and economic aspects to those involving ecology itself, as well as social and cultural dimensions, which are ultimately reflected in social change (Davidson, 2019). Energy demand is expected to increase significantly in the near future as energy resources decline; consequently, innovative solutions, both technological and non-technological, as well as clean energy production, are necessary and desirable (Yilbaşi et al., 2023).

As a global region, Latin America continues to be a leader in the use of clean energy. Furthermore, it is a region with a high concentration of cities severely affected by climate change. Climate vulnerability is evident in both urban and rural areas through extreme heat, changes in precipitation patterns, reduced viability of hydrological systems, and the erosion of natural habitats and biodiversity. Guatemala, Honduras, and El Salvador are among the most climate-vulnerable countries in the world, while in the Caribbean, the climate crisis and rising sea levels have become direct existential threats (Masson et al., 2021). Although a climate-compatible energy transition is considered essential for slowing the pace of climate change, it is currently at risk due to the persistent effects of the COVID-19 pandemic (Nagao & Vedovato, 2023; Hampl, 2021), exacerbated by Russia's war against Ukraine and the subsequent boom in fossil fuel energy markets.

Many countries in the region are currently deciding between the "race to net zero" (decarbonizing their economies) and the "race to the bottom" (energy-intensive development), where "race" refers to competition among Latin American jurisdictions to offer the lowest cost of negative externalities, that is, the lowest social and environmental governance standards (Dammert et al., 2021; Pye et al., 2020). Inevitably, the "race to the bottom" would exacerbate pre-existing regional challenges, generalized in this study as the Sustainable Development Goals (SDGs) in which Latin America has the lowest scores (Ibrahim et al., 2023): SDG 9, through the adoption of outdated industrial processes and standards; SDG 10, by further entrenching inequality; and SDG 16, due to institutional failures in protecting the public interest.

Redirecting Latin America's economic recovery toward an energy transition that takes these pre-existing challenges into account would have the advantage not only of reducing emissions but also of potentially decreasing inequality, strengthening industrial standards, and improving institutions. Conversely, supporting the traditional business model implies replicating the failures that have been found to lead to inefficiencies at multiple levels, including the inefficiency of inequality (UNDP, 2021; CEPAL, 2021).

This explains the lack of studies that analyze the problem from the reality of the different countries of Latin America, particularly the issue of energy transition from a regional perspective that allows for a greater understanding of this phenomenon, as has occurred in advanced economies. The present study seeks to characterize the energy supply, both globally and among the most innovative economies, and to use this information as a point of comparison for analyzing the situation in Latin America. Secondly, it aims to evaluate the variables and identify patterns of energy supply across different countries and selected years in order to deduce the energy management practices and policies that these economies have implemented. Based on this analysis, we will propose public policy guidelines that could support the promotion of the energy transition toward renewable energy sources in Latin America.

Research Problem

Although per capita CO_2 emissions in Latin America remain lower than in the rest of the world, the growing energy demand, which is double the global average, raises the question of whether this increase will be met through greater production and supply of energy from fossil fuels or predominantly through renewable energy sources (Washburn & Pablo, 2019). The expansion of megacities has led to greater consumption of fossil fuels, contributing to high levels of environmental pollution, health problems, and environmental degradation.

Central America, Mexico, and the Caribbean still depend heavily on fossil fuels, while other countries are beginning to replace renewable energy sources with fossil fuels, particularly in electricity generation (De Queiroz et al., 2019). Gas-fired generation is the most important source of electricity after hydropower, accounting for 25% of electricity generation (Balza et al., 2016). The high dependence on imported fossil fuels (liquid petroleum products and derivatives, and natural gas) in the Caribbean Small Island Developing States (SIDS), where up to 90% of commercial energy comes from imported oil (Trinidad and Tobago, Suriname, Curaçao, Jamaica, and others), generates inefficiencies in the acquisition and use of energy resources, as high percentages of GDP are spent on imported fossil fuels (Menezes & Vedovato, 2023).

To decouple economic growth from Greenhouse Gas (GHG) emissions and harmful fluorinated gases, it is necessary to drastically reduce the carbon intensity of the main emitting sectors (fuel combustion, agriculture, and Land Use, Land-Use Change, and Forestry (LULUCF)) in order to achieve the objectives of the Paris Agreement. This involves transforming the energy matrix toward a greater share of renewable energy and opting for clean electricity instead of investing in additional coal- or gas-fired power plants (Hwang & Sánchez, 2024).

Renewable energy is now the least costly option in the electricity sector. Variable Renewable Energy (VRE) is driving the ongoing decarbonization of the electricity sector, transforming the operation of power systems (Tamimi & Paramita, 2025). While rapid growth in variable renewable energy (VRE) contributes to improved energy efficiency and mitigates concerns regarding fuel security (where renewable energy sources are locally available), it will simultaneously require increased flexibility in electricity systems, where distributed photovoltaic energy is expected to replace fossil-fuel power plants currently in use, motivated in part by the significant decline in renewable energy costs.

For example, if the 31 countries of the Caribbean subregion (mainly small island states) adopt 90% clean energy by 2030, this would not only benefit human and environmental health but also generate annual savings of US$9 billion in fuel costs (Lazaro & Serrani, 2023). New energy technologies and products (e.g., dispatchable generation, demand response, storage, digitalization, and interconnection) have not yet been fully implemented to adapt to these increases; others are still under development or in the demonstration phase (OECD, 2019).

Several countries, such as Costa Rica, Brazil, Chile, Colombia, and the Dominican Republic, have made progress in distributed generation, although the regulatory framework requires further development and regulatory and bureaucratic barriers still need to be removed (Howell, 2021). In other words, Latin American countries can help drive energy innovation supported by the rapid adoption of renewable energy or the rapid decarbonization of the gas sector, which in turn increases productivity and energy efficiency while reducing costs. However, given the complexity of the challenges associated with the energy transition, the following research question arises: What are the determinants that influence the energy transition in Latin America?

Methodology

The present research is framed within the quantitative approach, as it is based on the collection and analysis of numerical data to examine the determinants of the energy transition in Latin America. The study design is non-experimental in nature, since the variables are not actively controlled but are only observed and analyzed in their natural settings to determine relationships and effects. The hypothetical-deductive method is employed to formulate hypotheses based on previous theories and observations regarding the determinants of the energy transition, which are then tested through the collection and analysis of empirical data.
The study population consists of Latin American countries, specifically those included in a dataset considered highly relevant to the energy transition. A total of 17 countries are considered: Argentina, Bolivia, Brazil, Chile, Colombia, Costa Rica, Ecuador, El Salvador, Guatemala, Honduras, Mexico, Nicaragua, Panama, Paraguay, Peru, the Dominican Republic, and Uruguay. Regarding sample size, annual data from 2000 to 2021 are selected for each of these countries, resulting in a dataset of approximately 374 observations (17 countries × 22 years).

Hypotheses

Null Hypothesis (H_0): There is no statistically significant influence of economic, social, and environmental indicators (such as renewable energy consumption, GDP per capita, foreign direct investment, CO_2 emissions, etc.) on the energy transition in Latin America.
Alternative Hypothesis (H_1): There is a statistically significant influence between economic, social, and environmental indicators (for example, renewable energy consumption, GDP per capita, foreign direct investment, CO_2 emissions, among others) and the energy transition in Latin America.

Panel Data

The analysis of the factors influencing the energy transition that will be included in the EPI in Latin America will use panel data, including cross-sectional analysis of multiple countries over time. This allows for a comprehensive study of the development of the energy transition in the region, taking into account both temporal changes and differences among countries (Greene, 2024).
For the analysis of the factors driving the energy transition in Latin America, panel data will be employed, including time series for several countries (cross-sections). Thus, the study presents an analysis of the evolution of the energy transition in the region across both time and countries.

$Y_{it} = \alpha + \beta X_{it} + \varepsilon_{it}$ (1)

Where:

- Y_{it} = the value of the energy transition indicator for country *i* in year *t*.
- X_{it} = the explanatory variables for country *i* in year *t*.
- α = the model constant.
- β = the vector of coefficients measuring the effect of the explanatory variables.
- ε_{it} = the error term, representing unexplained variation.

Model Equation

The methods used to estimate the Fixed Effects (FE) and Random Effects (RE) models and to test consistency using the Hausman test are described in this section. These models are applied to variables that consider various economic and environmental elements involved in the energy transition in Latin America.

Estimation of the Fixed Effects (FE) Model

The Fixed Effects (FE) model is applied to estimate the effect of time-varying factors while controlling for country-specific characteristics that do not vary over time (Freeman et al., 2025). The model can be written in the following general form:

$RNE_{it} = \alpha + \beta_1 UP_{it} + \beta_2 GDP_{it} + \beta_3 CO2_{it} + \beta_4 CIB_{it} + \beta_5 ICO2_{it} + \beta_6 N2O_{it} + \beta_7 PEW_{it} + \beta_8 PRE_{it} + \beta_9 FBKF_{it} + \beta_{10} RRN_{it} + u_i + \varepsilon_{it}$ (2)

Where:

- RNE_{it}: Renewable energy consumption as a percentage of total final energy consumption for country *i* in year *t*.
- α: Model intercept, representing the expected value of RNE when all independent variables are zero.
- $\beta_1, \beta_2, \beta_3 \ldots \beta_{11}$: Regression coefficients indicating the impact of each independent variable on renewable energy consumption.
- UP_{it}: Urban population in country *i* in year *t*.
- GDP_{it}: GDP per capita (constant 2010 US$).
- FDI_{it}: Foreign direct investment as a percentage of GDP for country *i* in year *t*.
- $CO2_{it}$: CO_2 emissions in metric tons per capita for country *i* in year *t*.
- CIB_{it}: Domestic credit to the private sector as a percentage of GDP for country *i* in year *t*.
- $ICO2_{it}$: Carbon intensity of GDP for country *i* in year *t*.

- N2O_it: N_2O emissions from buildings for country *i* in year *t*.
- PEW_it: Electricity production from oil as a percentage of total electricity production for country *i* in year *t*.
- PRE_it: Electricity production from renewable sources (excluding hydropower) in kilowatt-hours for country *i* in year *t*.
- FBKF_it: Gross fixed capital formation as a percentage of GDP for country *i* in year *t*.
- RRN_it: Total natural resource rents as a percentage of GDP for country *i* in year *t*.
- ε_it: Error term capturing unexplained variation in renewable energy consumption.

Estimation of the Random Effects (RE) Model

The Random Effects (RE) Model is a statistical econometric method used in panel data studies, based on the assumption that there are random characteristic differences among individuals (in our case, among different countries) that are not correlated with the explanatory variables in the model (Bell et al., 2019). This, in turn, allows for the inclusion of country-specific effects as well as time effects and improves estimation efficiency by exploiting variation across countries.

$RNE\_it = \alpha + \beta_1 UP\_it + \beta_2 GDP\_it + \beta_3 CO2\_it + \beta_4 CIB\_it + \beta_5 ICO2\_it + \beta_6 N2O\_it + \beta_7 PEW\_it + \beta_8 PRE\_it + \beta_9 FBKF\_it + \beta_{10} RRN\_it + u\_i + \varepsilon\_it$ (3)

Where:

- RNE_it: Renewable energy consumption as a percentage of total final energy consumption for country *i* in year *t*.
- α: Model intercept, representing the expected value of RNE when all independent variables are zero.
- β_1, β_2, β_3 ... β_{11}: Regression coefficients indicating the impact of each independent variable on renewable energy consumption.
- UP_it: Urban population in country *i* in year *t*.
- GDP_it: GDP per capita (constant 2010 US$).
- FDI_it: Foreign direct investment as a percentage of GDP for country *i* in year *t*.
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Aplicación Application of the Hausman Test

The Hausman test is necessary to determine whether the fixed effects model or the random effects model is more appropriate for the analysis. The test examines whether the explanatory variables are correlated with the unobserved individual effects. Specifically, it evaluates whether there is a systematic correlation between the regressors and the unobserved individual effects (Rüttenauer & Ludwig, 2023).

Under the null hypothesis, it is assumed that the individual effects are not correlated with the explanatory variables, which would favor the random effects model due to its efficiency. However, if the test rejects the null hypothesis, this would indicate the presence of such a correlation, suggesting that the fixed effects model is the more appropriate specification, since it robustly controls for this inherent endogeneity by eliminating time-invariant unobserved effects (Wang et al., 2025).

The Hausman test formula is expressed as:

$$\mathbf{H = (b\_fe - b\_re)' \times [Var(b\_fe) - Var(b\_re)]^{(-1)} \times (b\_fe - b\_re)} \quad (4)$$

Results

The descriptive statistics table provides an initial overview of twelve key variables, ranging from renewable energy consumption to economic and environmental indicators. Data dispersion is notable across several variables, such as Urban Population (UP), which shows a mean of 23.5 million and a standard deviation of 41.7 million, indicating substantial heterogeneity in urban population size among the observations. Similarly, Electricity Production from Renewable Sources, Excluding Hydropower (PRE), with a mean of 4.88E+09 kWh and a standard deviation of 1.63E+10 kWh, suggests wide variations in the development of these technologies, which may reflect differing levels of investment and energy policies among the entities studied. The minimum and maximum values confirm this variability, with extremely wide ranges suggesting the inclusion of economies at different stages of development and with diverse productive and demographic structures (Zaman & Valiyattoor, 2025).

Table 1. Descriptive Statistics of the Variables

Variable	Mean	Std. Dev.	Mínimum	Maximum
RNE	34.21	17.62	7.65	70.41
UP	23,500,000	41,700,000	1,867,017	187,000,000

GDP	6,830.77	3,902.45	1,429.73	16,192.16
FDIS	0.6	1.46	-7.56	8.1
CO2	1.94	1.08	0.67	4.83
CIB	38.82	19.49	9.5	94.73
ICO2	0.136	0.042	0.063	0.219
N2O	0.321	0.572	0.0063	2.48
PEW	21.23	22.09	0.0008	92.51
PRE	4.88E+09	1.63E+10	-8.79E+09	1.45E+11
FBKF	20.41	4.69	11.69	40.2
RRN	3.71	3.88	0.02	18.96

Note. Author's own elaboration.

In economic terms, GDP per capita (GDP) has a mean of US$6,830.77 and a standard deviation of US$3,902.45, indicating considerable disparity in the level of economic development among the units of analysis. This variability is also evident in Foreign Direct Investment, net capital outflows (FDIS), which, with a mean of 0.6% and a standard deviation of 1.46%, exhibits both negative values (capital outflows) and positive values, reflecting complex dynamics in investment flows. Gross Fixed Capital Formation (FBKF), with a mean of 20.41% and a standard deviation of 4.69%, remains within a narrower range, which may indicate relatively more stable investment in fixed assets compared to other variables (UNCTAD, 2023).

From an environmental perspective, CO_2 Emissions (CO2) per capita average 1.94 metric tons, with a standard deviation of 1.08, suggesting differences in individual carbon footprints. Carbon Intensity of GDP (ICO2), with a mean of 0.136 kg CO_2e per PPP dollar of GDP and a low standard deviation of 0.042, indicates that despite variations in per capita emissions, carbon efficiency in economic production may be more consistent. On the other hand, Nitrous Oxide Emissions (N2O), with a mean of 0.321 Mt CO_2e and a standard deviation of 0.572, exhibit high variability, possibly due to the diversity of energy sources or industrial practices (Vita, 2018).

Finally, variables related to the energy sector and natural resources reveal interesting patterns. Renewable Energy Consumption (RNE), with a mean of 34.21% of total energy consumption and a standard deviation of 17.62%, underscores the uneven efforts toward energy transition, while Electricity Production from Oil (PEW), with a mean of 21.23% and a high standard deviation of 22.09%, emphasizes the persistence of oil in the energy matrix of some regions. Total Natural Resource Rents (RRN), with a mean of 3.71% of GDP and a standard deviation of 3.88%, indicate the varying importance of these resources in national economies, which may influence investment in renewable energy and environmental policies (Hidalgo & Hernández, 2021).

Table 2. Fixed Effects and Random Effects Models

Variable	**Coef. (Efectos Fijos)**	**p-valor (Efectos Fijos)**	**Coef. (Efectos Aleatorios)**	**p-valor (Efectos Aleatorios)**
UP	-5.30E-08	0.517	-6.97E-08	0.301
GDP	0.0022099	0.000 ***	0.0021886	0.000
FDIS	0.4838045	0.000 ***	0.4943755	0.000 ***
CO2	-12.24801	0.000 ***	-12.44343	0.000 ***
CTB	-0.0655635	0.003 ***	-0.0617178	0.004 ***
ICO2	44.06468	0.017 **	40.44866	0.026 **
N2O	6.323669	0.038 **	6.492072	0.031 **
PEW	0.0712872	0.001 ***	0.073617	0.001 ***
PRE	3.19E-11	0.242	3.72E-11	0.121
FBKF	-0.2132161	0.001 ***	-0.2000958	0.001 ***
RNN	-0.0708015	0.312	-0.0718381	0.302
α	41.16702	0.000 ***	42.26219	0.000 ***

*****Note. The significance of each variable is subject to the following thresholds: *p < 0.10; **p < 0.05; *p < 0.01.***

The fixed effects model presented investigates the factors influencing renewable energy consumption (RNE) in 17 Latin American countries during the period 2000–2021. The overall robustness of the model is notable, as evidenced by an Fstatistic of 22.64 with a probability of 0.000, supporting the joint significance of the explanatory variables in explaining variations in renewable energy consumption. The within R^2 value of 0.4353 is particularly relevant, indicating that approximately 43.5% of the variability in renewable energy consumption within each country over time can be attributed to the model.

Furthermore, the F-test for fixed effects ($F(16, 323) = 312.07$, $p < 0.01$) clearly justifies the choice of the fixed effects model over a pooled OLS model, suggesting the existence of unobserved, country-specific heterogeneity that remains constant over time and that, if not controlled for, could bias the results.

When analyzing the coefficients associated with the variables, statistically significant relationships with renewable energy consumption are identified. GDP per capita (GDP) exhibits a positive and highly significant relationship (coef. 0.0022, $p < 0.01$), indicating that as countries increase their wealth, they tend to increase their consumption of renewable energy, in line with the Environmental Kuznets Curve theory.

Similarly, electricity production from oil (PEW) and foreign direct investment (FDIS) also show positive and significant relationships. However, important trade-offs are identified: CO_2 emissions (coef. -12.25), domestic credit to banks (CIB), and gross fixed capital formation (FBKF) have a negative and significant impact on renewable energy consumption. This latter finding may suggest that capital investments are being directed primarily toward non-renewable sectors, thereby crowding out investment in clean energy.

The lack of statistical significance of Urban Population (UP) as a determinant of renewable energy consumption (RNE) challenges some initial intuitions. Theoretically, a greater concentration of population in urban areas could be expected to drive energy demand and, consequently, the need to diversify the energy mix toward more sustainable sources. However, this result may indicate that urbanization per se is not a direct factor, but rather that its impact is mediated by other unobserved variables or by contextual factors specific to the regions studied. For example, in cities of developing economies, urban growth is often accompanied by an expansion of existing energy infrastructure predominantly based on fossil fuels, without an immediate transition toward large-scale renewables (Muñoz, 2022). Alternatively, the implementation of urban energy policies and citizens' environmental awareness may be more influential than the mere size of the urban population (Garlet, 2021). It is possible that heterogeneity in urban planning and development priorities across the different units of analysis dilutes any direct effect of urbanization on RNE, suggesting that the relationship is more complex and multifaceted.

The fact that Electricity Production from Renewable Sources (excluding hydropower, PRE) does not show a significant relationship with Renewable Energy Consumption (RNE) is a particularly counterintuitive finding, given that greater renewable electricity generation should logically contribute to higher overall renewable energy consumption. This disconnect may be due to several reasons. First, it is possible that PRE production is exported, or that renewable energy consumption in other forms (heating, transportation) is dominant and offsets any effect of renewable electricity on total consumption. Second, there may be a time lag between PRE production and its reflection in consumption, or the installed PRE capacity may not yet be large enough to generate a statistically discernible impact on aggregate RNE across the regions. A more detailed analysis of the composition of final energy consumption and the capacity of transmission networks to integrate renewable energy may be necessary to unravel this apparent paradox (IRENA, 2024). It is important to consider that renewable energy consumption encompasses more than electricity alone, including the direct use of biofuels, solar thermal energy, and other sources, which may dilute the direct impact of renewable electricity production on the RNE metric.

The lack of significance of Natural Resource Rents (RRN) in relation to Renewable Energy Consumption (RNE) is also noteworthy. A priori, countries with high natural resource rents, especially from fossil fuels, might have fewer incentives to invest in and adopt renewable energy due to the "resource curse" (Ross, 2012), leading to a negative relationship. However, the absence of significance suggests that the relationship is neither linear nor unidirectional. On the one hand, some resource-rich countries may be using these rents to finance the energy transition and diversify their economies (Altinoz & Dogan, 2021). On the other hand, global pressure and international climate agreements may be encouraging renewable energy adoption regardless of resource wealth. This statistical neutrality may reflect a combination of these opposing effects or indicate that decisions to invest in renewables are influenced more by factors such as government policies, technology costs, and energy security than by the availability of natural resource rents.

Likewise, the absence of significance in natural resource rents suggests that the phenomenon known as the "resource curse" does not have a direct effect on lower renewable energy adoption according to this specific dataset. This analysis provides a robust empirical basis for understanding the complex economic and structural factors influencing the energy transition in Latin America.

Table 5 presents the results of the estimation of a Random Effects (RE) model, which offers an alternative to the Fixed Effects (FE) model for panel data analysis. The RE model is based on the premise that the unobserved individual effects of each country (u_i) are not related to the explanatory variables. This fundamental assumption, specified in the table as Corr(u_i, X) = 0 (assumed), allows the model to be more efficient than the FE model, as it exploits both temporal variation within countries and variation between countries.

The R-squared values are comparable to those of the FE model, reaching an overall R^2 of 0.4766, indicating that the model explains approximately 48% of the total variability in renewable energy consumption. The rho value (0.959) is remarkably high, suggesting that nearly 96% of the total variance of the composite error term is attributable to country-specific individual effects (u_i), which underscores the relevance of unobserved heterogeneity among nations.

When examining the individual coefficients, the findings are highly consistent with those obtained from the FE model. Variables such as GDP per capita (GDP), foreign direct investment (FDIS), carbon intensity (ICO2), nitrous oxide emissions (N2O), and electricity production from oil (PEW) continue to show a positive and statistically significant

relationship with renewable energy consumption. Similarly, CO_2 emissions, domestic credit (CIB), and gross fixed capital formation (FBKF) maintain their negative and significant impact.
Both the magnitude and sign of the coefficients, as well as their level of significance (reflected in the z-values and p-values), exhibit only minor differences between the RE and FE models. This consistency in results constitutes an important finding in itself. However, the final decision regarding which model to adopt should not be based solely on this similarity in coefficients; it is crucial to evaluate the validity of the central assumption regarding the absence of correlation between individual effects and regressors. To do so, conducting the Hausman test is indispensable.

Discussion

The present analysis of the factors influencing renewable energy consumption (RNE) in 17 Latin American countries during the period 2000–2021, based on a panel data model, establishes a valuable connection with the current academic literature. The methodological robustness, evidenced by the selection of a Random Effects model following rigorous specification tests (Hausman) and the correction of heteroskedasticity and autocorrelation issues, provides strong internal validity to the findings. This methodology is consistent with that employed in other regional and global studies in the field (Lin & Omoju, 2017; Marques & Fuinhas, 2012), thereby allowing direct comparison of our results with a broader research framework and offering specific and contextualized evidence for the Latin American region.
A strong agreement with the literature is observed regarding the positive and statistically significant relationship between Gross Domestic Product per capita (GDP) and renewable energy consumption (coef. 0.0021886, $p < 0.01$). This finding empirically validates for Latin America the hypothesis that more prosperous countries possess a greater capacity and, often, a stronger inclination to finance and adopt the energy transition. This result aligns perfectly with Cheikh and Zaied (2024), who argue that economic development facilitates investment in renewable infrastructure and clean technologies, as well as with Zhang et al. (2023), who identify economic growth as a key driver of renewable energy adoption at the global level.
This positive relationship has been extensively documented across various regions. For example, Apergis and Payne (2010), in their study of emerging economies, found bidirectional causality between renewable energy consumption and economic growth. Similarly, Sadorsky (2009) identified a positive relationship in G7 countries. The results of our study suggest that economic development in Latin America acts as a facilitator rather than an obstacle to the transition toward cleaner energy sources, in contrast to the hypothesis that developing countries prioritize growth at the expense of sustainability. This may be because, as economies grow, fiscal and private resources are generated that can be allocated to investments in renewable technologies, the creation of carbon markets, or the implementation of subsidies and promotional policies. Moreover, higher per capita income is often accompanied by greater environmental awareness and increased public demand for sustainability policies, thereby creating a favorable environment for RNE (Omri et al., 2015).
A crucial aspect of our findings is the positive and significant impact of Foreign Direct Investment (FDIS) on renewable energy consumption (coef. 0.4943755, $p < 0.01$). This result strongly supports the concept of the “Halo Effect” or “Technology Transfer Hypothesis” associated with FDIS, as discussed by Setiawan and Nihayah (2023) and Zafar et al. (2020). These authors argue that FDI not only provides the capital necessary for renewable energy projects but also facilitates the transfer of advanced technologies, specialized knowledge, managerial skills, and best environmental practices from more developed investor countries to recipient economies. This is particularly relevant for Latin America, where the technological gap in renewable energy can be substantial. FDI therefore not only directly promotes the construction of renewable energy plants but also catalyzes the development of local value chains, improves energy efficiency, and promotes higher sustainability standards. This finding reinforces the notion that openness to international investment is fundamental for accelerating changes in the regional energy matrix, a conclusion consistent with the observations of Quito et al. (2023) regarding the driving role of investments in energy efficiency.
However, as previously noted, this positive effect of FDIS may be partially amplified by a possible “halo effect” associated with countries that are already leading the energy transition. Countries that already demonstrate a commitment to renewable energy, reflected in their consumption patterns, policies, and environmental reputation, are often more attractive to sustainability-oriented FDI. As Thorndike (1920) noted in his conceptualization of the halo effect, a favorable overall impression can lead to the attribution of other positive characteristics, which in econometric terms may translate into endogeneity issues or omitted variable bias (Wooldridge, 2010). This bias could be inflating the observed magnitude of the FDIS coefficient. Future research should incorporate indicators of energy policy or environmental governance that capture this reputational dimension. In addition, conducting robustness tests that temporarily exclude the countries most advanced in the transition could verify the stability of the results and isolate the specific impact of FDIS on renewable energy consumption while minimizing the influence of this potential bias.
The study presents results that qualify or complicate some previous conclusions, revealing the complexity of the energy transition in Latin America. The negative and significant coefficient of CO_2 emissions (coef. -12.44343, $p < 0.01$) on renewable energy consumption may be interpreted as evidence of the phenomenon known as “path dependence” or “carbon lock-in” (Seto et al., 2016). Economies with a high carbon footprint, driven by infrastructure and industrial processes that are heavily dependent on fossil fuels, face significant structural barriers to dismantling these systems (Unruh, 2000). This finding underscores that achieving an effective energy transition requires not only adding new renewable capacity but also overcoming the inertia associated with inherited socio-technical regimes, as described by Guo et al. (2019). This implies that countries with high levels of CO_2 emissions possess a more rigid energy structure and therefore face greater difficulty in incorporating and consuming renewable energy on a large scale.
Particularly significant is the negative and significant coefficient of Gross Fixed Capital Formation (FBKF) (coef. -0.2000958, $p < 0.01$). While authors such as Rasoulinezhad et al. (2023) emphasize capital scarcity as a general obstacle

to the energy transition, our result suggests a more subtle and concerning problem in Latin America: the direction of investment flows. The evidence indicates that despite total investment in fixed capital, a considerable proportion of this investment is being directed toward carbon-intensive sectors or infrastructure that does not support the integration of renewable energy, thereby creating inertia that hinders progress toward greater RNE. This may be due to the persistence of investments in extractive industries or fossil fuel infrastructure, which are capital-intensive but generate limited positive impacts on renewable energy consumption. This phenomenon has been documented in other regions by authors such as Majeed et al. (2018), who argue that fixed capital investment in developing economies often prioritizes the expansion of existing productive capacity, which may be linked to conventional energy sources. This implies that public policies should focus not only on increasing investment levels but also on strategically directing them toward economic decarbonization and renewable energy infrastructure, possibly through fiscal incentives or specific regulations.

The negative and significant coefficient of Domestic Credit to the Private Sector (CIB) (coef. -0.0617178, $p < 0.01$) is an unexpected and crucial result. A priori, greater access to credit would be expected to facilitate investment in any sector, including renewable energy. However, our findings suggest that in Latin America, domestic credit is not flowing predominantly toward renewable energy projects. This may be due to several factors: the banking sector may perceive renewable energy projects as riskier, there may be a lack of appropriate financing mechanisms for green projects, or credit may be channeled toward traditional industries that compete with renewable energy deployment (extractive industries and energy-intensive conventional manufacturing). This result contrasts with studies that find a positive effect of financing on renewable energy investment in developed economies (Brunnschweiler & Bulte, 2008) and highlights the need for specific policies to "green" the financial system and direct capital toward the energy transition in the region.

Conclusion

The analysis of the energy transition is grounded in a solid foundation of economic and environmental theories that explain both the factors driving it and those that constitute its obstacles. Externalities Theory supports the need for government intervention to remedy market failures arising from the social costs associated with fossil fuels, including climate change. On the other hand, the Theory of Induced Technological Change and Endogenous Growth Theory address how such policies, by altering economic incentives, foster innovation and increase investments in research and development (R&D) aimed at sustainable technologies, thereby accelerating their adoption. Nevertheless, Path Dependency Theory warns about the resistance of existing energy systems (lock-in), which complicates change even when alternatives are available. Finally, Green Growth Theory presents an optimistic perspective by asserting that this transition is not only crucial for achieving environmental sustainability but also represents an opportunity to decouple economic growth from environmental degradation and promote a new development model.

The descriptive analysis of the determinants of the energy transition in Latin America between 2000 and 2021 reveals a region characterized by heterogeneity and complex trends. While significant progress can be observed, such as the exponential growth of non-conventional renewable energy sources (Figure 21) and a drastic reduction in dependence on oil for electricity generation (Figure 19), total renewable energy consumption shows a slight decline throughout the period, interrupted only by the economic contraction of 2020 (Figure 1). The behavior of key economic variables, such as GDP per capita (Figure 5), investment (Figure 23), and natural resource rents (Figure 25), demonstrates strong procyclicality and vulnerability to global economic cycles. At the national level, developments are uneven: while countries such as Brazil and Mexico lead the expansion of new renewable energy sources (Figure 22), and Central American nations exhibit a historically high dependence on hydropower (Figure 2), others such as Chile, Argentina, and Mexico display the highest per capita emissions (Figure 12). This structural diversity in energy matrices, economic development, and financial deepening underscores that there is no single transition pathway for the region, but rather multiple trajectories conditioned by the economic, geographic, and political particularities of each country.

According to the results of the econometric analysis, and after validating the suitability of the Random Effects model through the Hausman test, several determinants of the energy transition in Latin America were identified. The main drivers are economic growth (GDP) and Foreign Direct Investment (FDIS), both of which show a positive and highly significant relationship with renewable energy consumption, suggesting that economic development and openness to external capital facilitate the adoption of clean technologies. However, important structural barriers remain: high CO_2 emissions, greater domestic credit to banks (CIB), and Gross Fixed Capital Formation (FBKF) exert a negative impact, indicating that carbon dependence and the allocation of investment toward non-renewable sectors hinder the transition process. On the other hand, variables such as urbanization (UP), non-conventional renewable energy production (PRE), and natural resource rents (RRN) were not found to be statistically significant determinants, implying that the transition in the region is driven more by structural economic factors and the direction of investment than by urban demographic growth or the so-called "resource curse."

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