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Research article

Institutional quality and financial development in the sustainable energy transition: Evidence from Latin America

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Abstract: The research analyzes how financial development and government effectiveness influence patterns of renewable energy adoption within a country's energy matrix. The study examines a sample of 16 Latin American countries based on 20 years of data (2002–2021). Using the two main variables, the Driscoll–Kraay estimator is applied; it is supplemented by complementary indices pertinent to governance and climate to facilitate a more comprehensive interpretation of the results and to integrate variable interactions to capture marginal effects. The direct results indicated that financial development has a significantly negative effect, as it does not, on its own, generate an investment pattern favoring renewable energy sources: meanwhile, governance effectiveness is shown to be statistically insignificant with respect to changes in the energy matrix. However, the results regarding the interaction between financial development and the complementary variable, climate readiness, indicate that the effect reverses once the interaction exceeds a threshold of +1.1 standard deviations (SD), turning positive at +1.2 SD. The dynamic between finance and governance interaction remains statistically insignificant. These results remain robust across tests employing various lag lengths and temporal segmentation. The study concludes that a transformation of the energy matrix, characterized by a greater share of renewable energy, is achievable when financial development aligns with investment planning facilitated by stable social, economic, and regulatory frameworks that enhance the capacity to channel financial resources into the execution of renewable energy projects. This result will help government entities, financial agents, and multilateral entities formulate and implement policies that are better aligned.

Keywords: renewable energy; government effectiveness; financial development; Driscoll–Kraay; Latin America

1. Introduction

The report by the International Energy Agency (IEA), in line with the outcomes of COP28 organized by the UN (United Nations), underscores the need for participating countries, including those in Latin America and the Caribbean, to triple their current renewable energy capacity. This is proposed as an effective means of limiting global warming to 2 °C by 2030. Such growth would offset the 6.4 metric tons of carbon dioxide equivalent (CO_2-eq) represented by their net per capita emissions [1,2]. The IEA notes that renewable sources generate more than 60% of the region's electricity and identifies the region's substantial solar, wind, and bioenergy resources. Nevertheless, the Latin American energy sector relies mainly on aging hydroelectric power plants. According to the Latin American and Caribbean Economic System (SELA), these plants account for 45% of energy generation. Currently, they face increasing downside risks due to disruptions to the hydrological cycle induced by climate change [3,4]. This transition presents a serious challenge. The IEA reports that investment in clean energy in emerging and developing economies fell by 8% in 2020, to below $150 billion. To achieve carbon neutrality by 2050, this figure must increase more than sevenfold, surpassing $1 trillion. Such an increase would yield significant economic and social benefits, but it would require large-scale efforts to improve the domestic environment for clean energy investment in these countries. International initiatives will also be needed to accelerate capital inflows [5]. Consequently, the mobilization of resources depends on two essential factors: functional domestic financial systems and stable public governance structures. The World Bank issued a statement summarizing the three main challenges facing the energy transition in Latin America. First, renewable energy projects have prohibitively high upfront capital costs, and many countries remain locked into costly, high-carbon energy options and inefficient subsidies. Second, developing countries face elevated capital costs that distort investment decisions by favoring conventional energy sources over renewables. Third, weak fundamentals within the energy sector, particularly regarding institutional capacities, hinder expansion and scaling up of this transition [6]. Various studies thus converge on the view that the State's role in implementing robust policies to support renewable energy projects, such as solar photovoltaic, wind, and hydroelectric power, is key. These initiatives must be integrated into national annual plans [7].

Beyond this region's specific evidence, recent global research highlights that the link between financial viability and the energy transition is not always linear. Instead, it is influenced by the new digital capabilities of the current generation. These capabilities are highly relevant for climate change preparedness and help enhance investment absorption capacity. Wang's study shows that artificial intelligence (AI) significantly promotes the transition to renewable energy, especially when financial development acts as a mediator. This effect increases when a threshold is surpassed [8]. In addition, Zhang's article asserts that AI's impact on sustainability is nonlinear. The use of renewable energy increases AI's contribution to reducing carbon intensity, reinforcing the importance of complementary structural conditions [9]. These findings support the idea that capital deepening leads to cleaner energy outcomes only under certain structural conditions, an issue that remains unresolved in Latin America. Previous studies have mainly focused on variables such as natural resource availability and specific incentives, such as regulated feed-in tariffs and renewable energy auctions. They rarely account for institutional heterogeneity or the interdependence among neighboring countries when similar energy policies spread. This factor is highly relevant in research of this type. According to Marra and Colantonio, results from a sample of European countries show that nations pursue the energy transition at different paces, depending on installed capacity and energy security. The absence of specific timeframes makes it impossible to determine when institutional quality becomes necessary for green finance development to have an effect [10], or whether such development alone can transform the share of renewables in the energy matrix.

Addressing this gap is the primary motivation for this study. This work makes three complementary contributions. First, it combines two main datasets for a comprehensive analysis: government effectiveness data from the Worldwide Governance Indicators (WGI) and the financial development index from the International Monetary Fund (IMF). The study also introduces the Climate Change Readiness sub-component from the ND-GAIN Index and the Per Capita Ecological Footprint as contextual variables. Readiness complements financial development, as investment absorption capacity stems from the latter [11]. The ecological footprint measures a country's environmental status [12]. This approach enables analysis of a sample of 16 Latin American countries over 2002–2021. Combining these factors with statistical methods allows a more precise identification of whether and how financial and governmental structures influence the energy matrix, as well as detection of marginal effects not visible in direct results. Second, the study introduces greater methodological rigor. The fixed-effects model uses Driscoll–Kraay robust standard errors to estimate the relationship. This corrects for heteroskedasticity, autocorrelation, and cross-sectional dependence among countries resulting from common shocks and regional policies. Adjustments like these are uncommon in Latin American academic literature and help prevent overestimating the influence of the financial system and regional policies. Third, the study examines two sub-periods (2002–2014 and 2015–2021) to add temporal value. This highlights changes following the introduction of green financial instruments such as green bonds, following the Paris Agreement, and verifies any impact on the energy matrix.

Figure 1 displays the analytical framework of this work. The rest of the article is organized as follows: start with a brief theoretical and empirical review, followed by the research hypothesis; Section 2, presents the data and methodology; Section 3, presents the main and robust results; Section 4, presents the discussion; and, finally, study's Section 5 presents the conclusions.

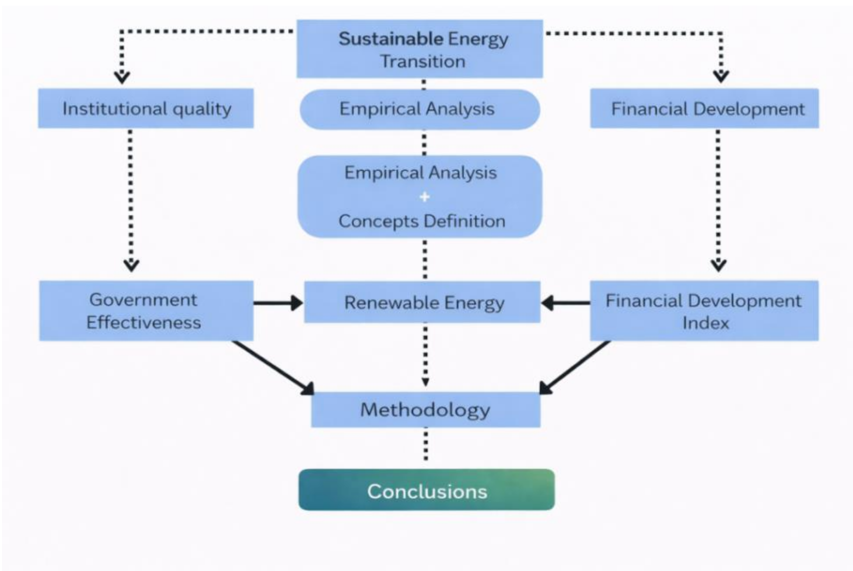

Figure 1. Analysis framework.

1.1. Literature review

1.1.1. Theoretical background

The relationship between financial development, institutional quality, and the energy transition can be understood through three complementary theoretical lenses: institutional economics, endogenous growth theory, and the political economy of the energy transition.

Institutional economics originally conceptualized institutions as the set of rules, norms, and structures that organize social behavior and shape economic performance [13]. Its subsequent evolution gave rise to new institutional economics (NIE), which preserves this foundational insight while placing greater emphasis on institutions as mechanisms designed to reduce uncertainty and transaction costs, thereby facilitating economic exchange [14,15]. Over time, this tradition has adapted to contemporary challenges such as globalization, technological change, and environmental protection through increasingly flexible institutional arrangements [15,16]. From this perspective, the theory provides a useful basis for understanding how institutional preparedness may facilitate the allocation of financial resources toward a wide range of investments, including clean energy projects, by reducing regulatory uncertainty and perceived investment risk [17].

Endogenous growth theory, in turn, establishes a direct link between financial development, innovation, and sustained growth. Unlike exogenous approaches, the endogenous framework associated with Romer explains growth as driven by internal factors such as knowledge accumulation, innovation, and human capital formation [18–20]. Within this perspective, finance is understood as a capital-allocation mechanism that channels resources toward productive activities and supports research, technological change, and innovation. Financial development, therefore, refers to the extent to which markets and institutions efficiently allocate investment flows and, in doing so, enhance productivity [18,21,22]. From this standpoint, public policies that promote human capital formation and research and development exert a direct influence on long-term growth dynamics [18,19]. Likewise, the structure of the financial system, whether bank-based or market-based, shapes the efficiency with which resources are allocated to innovative sectors [23]. Financial intermediaries such as banks and venture capital funds may thus serve as agents of knowledge transfer, supporting entrepreneurship and innovation [24,25]. Applied to the present study, this perspective suggests that renewable energy adoption is more likely to accelerate in regions with deep financial markets operating within stable, supportive institutional environments [26,27].

Finally, the political economy of the energy transition emphasizes that "green" capital flows are more likely to succeed where robust policies and administrative systems capable of implementing them are already in place [28]. This perspective also anticipates nonlinear effects: in countries with weak governance, greater financial deepening may continue to favor conventional, lower-risk projects; by contrast, once a certain institutional threshold is crossed, private capital can become a driver of decarbonization. The energy transition is embedded within broader political and economic structures that often continue to privilege fossil fuels, a dynamic that may actively undermine transition efforts [29]. At the same time, the concept of a just transition underscores the importance of equitably distributing the costs and benefits of energy transformation [30,31]. In this context, the strength of governance systems, including legislation, regulatory bodies, and implementation strategies, plays a decisive role in reducing uncertainty and attracting investment in renewable energy [32,33]. Recent work on renewable energy policy regimes suggests that policy output can also be understood in terms of the density and intensity of policy instruments, thereby offering a complementary lens for assessing how strongly states support renewable energy transitions over time and across political contexts [34]. This is especially relevant because changes in the political climate may affect not only the existence of policy support but also its consistency, scope, and credibility. Nevertheless, states continue to face major challenges in pursuing environmental goals, given that political decisions operate within market systems that may either facilitate or resist such transformations [35–37]. International climate commitments increasingly intensify these pressures by requiring both public and private actors to align their actions with broader environmental objectives [38]. In sum, these three perspectives converge on a central proposition: Although finance and governance are both essential, their contribution to renewable energy deployment materializes only when institutions reach a minimum level of quality sufficient to reduce regulatory risk and sustain long-term public and private investment.

1.1.2. Empirical literature review

The relationship between finance and the energy transition has been examined primarily in advanced economies, where the evidence suggests that its effects depend heavily on the quality and credibility of regulation. Steffen et al. provide a global meta-analysis of the weighted average cost of capital (WACC) for solar and wind projects across multiple countries and show that differences in financing conditions, linked to financial-market development and regulatory frameworks such as carbon pricing, significantly affect WACC and, therefore, the economic viability of renewable energy projects [39]. Baker shows that U.S. municipal green bonds reduce the required rate of return by an average of 6 basis points (bps), but only when they satisfy the environmental regulatory attributes valued by investors [40]. More recent post-Paris evidence reinforces this conditional interpretation. Tolliver et al. show that green bonds have become increasingly relevant for financing Paris-aligned renewable energy and sustainable development goals, particularly when supported by credible policy frameworks and long-term investment signals [41]. Rasoulinezhad and Taghizadeh-Hesary similarly argue that green finance can promote renewable energy development and energy efficiency, although its effectiveness varies substantially across countries depending on financial infrastructure and institutional conditions [42].

This broader pattern is also reflected in more region-specific evidence. Research on renewable energy financing in India suggests that private capital plays a major role in photovoltaic deployment and that regulatory transparency, including economic, social, governance (ESG) mandates, can increase investor confidence by 1.5 to 3 times, according to some models [43]. Similarly, recent policy reviews in Southeast Asia indicate that green bond markets can support renewable energy and energy efficiency, but that their effectiveness depends heavily on de-risking measures, implementation quality, and policy design rather than on financial deepening alone. In China, green finance has been found to promote renewable energy consumption and installed capacity, with stronger effects in provinces characterized by higher levels of regulatory development, including increases of roughly 10–20% mediated through research and development (R&D) and market-based channels [44]. More recent empirical research further shows that this relationship remains heterogeneous even within a strong national framework: Lee et al. find that green finance promotes renewable energy in China [44], whereas Sun et al. show that these effects vary across regions, indicating that sub-national policy and institutional conditions remain decisive [45]. Other spatial analyses suggest that green bonds reduce carbon intensity by approximately 0.3% for every 1% increase in emissions, with the effect mediated by changes in the energy matrix in regions characterized by better governance [46]. Overall, the recent international literature increasingly suggests that the finance-renewables nexus is conditional rather than automatic, and that current empirical debates focus less on whether finance matters than on the regulatory and institutional conditions under which it can effectively support low-carbon investment.

In Latin America, by contrast, the literature remains more limited in scope, although post-2015 research has begun to provide more direct evidence on sustainable finance instruments. In the Brazil, Russia, India, China, South Africa (BRICS) economies, financial market depth has been found to positively affect renewable energy and economic growth, although these effects are strengthened by institutional stability and quality [47]. Another illustrative case is Chile, where competitive tenders secured 777 gigawatt-hour (GWh) of solar energy at USD 37 megawatt-hour (MWh) under an institutional framework designed to preserve competition; in parallel, the Santiago Stock Exchange began listing renewable energy firms, thereby facilitating access to finance [48]. Yet, this case appears to be more the exception than the norm in the region. More recent evidence confirms both the progress and the limitations of sustainable finance markets in Latin America. González et al. offer one of the most up-to-date analyses of green bonds for renewable energy in Latin America and the Caribbean, showing that renewable energy is already a major use of proceeds, but that issuance remains concentrated, and market expansion continues to face constraints related to transparency, market depth, and institutional credibility [49]. Most Latin American economies also continue to confront the problem of modest or small greeniums, which are insufficient on their own to generate large-scale expansion without stronger political and institutional backing. According to an Organisation for Economic Co-operation and Development (OECD) report covering more than 100 bond issuance between 2014 and 2024, average spreads ranged from 5 to 12 basis points, depending on certification and market conditions; on their own, these figures are insufficient to meet the scale required by the energy transition [50]. As this literature increasingly suggests, the financial channel does not operate solely through formal regulation, but also through broader structural factors related to the state's capacity to convert investment flows into tangible outcomes, including climate readiness and project-execution capabilities. In this sense, green finance is increasingly understood not as a substitute for institutional readiness, but as a complement to it.

The literature has also expanded in directions directly relevant to the present study. One recent strand examines the role of digital capabilities, particularly AI, in supporting the energy transition. These applications include defect inspection and detection, predictive failure analysis for preventive maintenance, and optimization of planning and grid integration. By using historical sensor data, such tools can reduce unexpected interruptions, extend project lifespans, and ultimately improve investment returns [51]. This is especially relevant here because the same literature documents nonlinear and conditional mechanisms in which the financial system acts less as a direct driver than as a facilitating channel in the transition. For example, recent research shows that AI development is associated with an acceleration of the renewable-energy transition, but that this effect is amplified only when financial development exceeds a certain threshold, suggesting that financial depth is not automatically "green" and that its contribution depends on complementary structural conditions [8]. Additional recent work on green finance in Asia similarly shows that the effects of financial instruments on renewable energy remain highly sensitive to domestic market structure and policy design, rather than being uniformly positive across contexts.

A further strand of literature relevant to the present study concerns the ecological footprint as an environmental diagnostic metric. By quantifying the extent to which resource consumption exceeds planetary biocapacity, the ecological footprint can help justify the expansion of renewable energy and support regulatory and financial commitments in economies such as the Group of Seven (G7) or the OECD [52]. Additional evidence from developing Asian countries suggests that renewable energy is directly associated with a reduced ecological footprint, underscoring the importance of well-targeted policy interventions [53].

Therefore, these studies reinforce the central premise of this research: the effects of key determinants, such as financial development and government effectiveness, on the energy transition depend not only on those variables themselves but also on facilitating conditions, such as climate readiness and ecological footprint. At the same time, the updated empirical literature shows that post-Paris research increasingly understands green finance as conditional on institutional quality, de-risking capacity, and project readiness. In this sense, the evidence most frequently cited in the field remains predominantly global in scope and still does not clearly identify how or under what conditions the financial channel, or the quality of governance, yields positive results specifically within the Latin American context. This is the gap the present study addresses. On this basis, three testable hypotheses are proposed:

Direct influence (H1): financial development and government effectiveness exerted a direct influence on the share of renewable energy in Latin American countries.

Moderating effect of the financial development (marginal effects) (H2): the interactions between financial development and readiness, as well as between financial development and government effectiveness, were statistically significant and positively associated with renewable energy shares.

Temporal and econometric robustness (H3): the results remained stable when incorporating an additional lag (lag 3), examining sub-periods (2002–2014 vs. 2015–2021), and excluding potential outliers (e.g., Paraguay).

2. Materials and methods

2.1. Conceptual framework

2.1.1. Sustainable energy transition

Geels [54] describes how the energy transition, replacing fossil fuel-based power systems with sustainable energy platforms, requires parallel technological, cultural, institutional, and financial system changes; moreover, the time scales can become a determining factor for the transformation. The definition can be broadened or refined based on various theoretical approaches and analytical dimensions. In this regard, Table 1 synthesizes the principal conceptualizations proposed by various authors, highlighting the central elements that each perspective deems relevant for understanding the phenomenon under study.

Table 1. Academic definitions of sustainable energy transition.

Sources	Definitions
Sgouridis & Csala (2014) [55]	A controlled process by which a technologically advanced society replaces all fossil energy inputs with "sustainable" renewable resources, while maintaining a sufficient level of energy services per capita.
Steg, Perlaviciute & van der Werff (2015) [56]	Involves broad changes in energy behaviors: adoption of renewable sources, efficient technologies, and investments in efficiency and demand management to achieve sustainable energy systems.
Kabeyi & Olanrewaju (2022) [57]	A roadmap that combines energy savings, improved generation efficiency, and fossil fuel substitution; it must integrate social, environmental, economic, technical, and institutional dimensions to be viable.
Yang et al. (2024) [58]	Conceives the transition as the alignment of the global renewable energy shift with the Sustainable Development Goals and the Paris Agreement, requiring deep decarbonization and policy coherence.
Niño Villamizar et al. (2023) [59]	A progressive process of rebalancing the energy matrix that reduces greenhouse gases (GHGs), guarantees sustainability without drastic economic impacts, and has become a central focus of the global geopolitical agenda.

Despite disciplinary nuances, the definitions converge on three key ideas: (i) gradual replacement of fossil fuels by renewable sources; (ii) the need to maintain energy security, equity, and affordability; and (iii) the integration of technological, social, economic, and institutional dimensions to achieve profound and lasting change. Sovacool [60] explains that the process requires protected areas that enable renewable technologies to mature before competing with established systems.

2.1.2. Financial development

Financial development is associated with the depth, accessibility, and efficiency of banking and capital markets [61]. Theoretically, greater depth reduces the cost of capital and diversifies risk [61,62]. However, recent studies suggest conditional effects: investment flows are directed toward fast-return sectors, including fossil fuels, when governance is weak [63]. Table 2, presented below, outlines other relevant definitions of the concept, highlighting the distinct theoretical perspectives and analytical dimensions proposed by various authors to explain its scope, functioning, and implications within the economy:

Table 2. Academic definitions of financial development.

Sources	Definitions
Levine (2005) [64]	Financial development occurs when instruments, markets, and intermediaries reduce information, compliance, and transaction costs, improving five functions: (1) information production and capital allocation, (2) monitoring and governance, (3) risk management and diversification, (4) savings mobilization and pooling, and (5) exchange facilitation.
Čihák et al. (2013) [65]	Conceptualize financial development through a “4 × 2” framework that assesses the depth, access, efficiency, and stability of both financial institutions and capital markets, providing a comprehensive map of the functioning of the financial system.
Beck, Demirgüç-Kunt & Levine (2010) [66]	Define and measure financial development using comparable indicators of size/activity, efficiency, and stability of banks, other institutions, stock exchanges, and bond markets, highlighting their usefulness for cross-sectional and temporal analysis.
King & Levine (1993) [67]	Argue that financial development is reflected in the services provided by intermediaries (monetary depth, predominance of commercial banking over the central bank, and credit to the private sector), which drive growth, capital accumulation, and efficiency.
Demirgüç-Kunt & Levine (2008) [68]	Emphasize that public policies shape financial development, understood as the emergence of contracts, markets, and institutions that mitigate information and transaction imperfections, expanding access to services and favoring long-term growth.

The definitions are related in that financial development describes a qualitative and quantitative improvement in the functions performed by the financial system: deepening, efficiency, access, and stability, achieved by reducing friction and allocating capital to productive uses, with a direct impact on innovation and economic growth.

2.1.3. Institutional quality

According to North [69], institutions plays by defining rules and reducing uncertainty; their quality is measured by the rule of law, control of corruption, and government effectiveness. Studies indicate that greater regulatory certainty is associated with lower risk premiums and, therefore, greater viability for capital-intensive renewable energy projects [70,71].

However, Table 3 presents other schools of thought surrounding this concept that are worth reviewing.

Institutional quality depends on the power and orientation of the rules, structures, and practices that govern economic and political operations. Good institutions reduce uncertainty while defending rights and allocating resources to production activities, but weak institutions enable rent-seeking, which impedes development progress.

Table 3. Academic definitions of institutional quality.

Sources	Definitions
Fernández Esquinas (2023) [72]	A set of cultural, regulatory, and organizational features of institutions that determine their functioning and the fulfillment of the missions for which they were created.
Kaufmann, Kraay & Mastruzzi (2010) [73]	Institutional quality (governance) encompasses the rules, enforcement mechanism and organizations through which power is exercised to manage a country's economic and social resources.
Hall & Jones (1999) [19]	Their concept of "social infrastructure" defines institutional quality as the set of government institutions and policies that shape the economic environment in which individuals and businesses acquire skills and accumulate capital.
Barbier & Burgess (2021) [74]	A broad concept that encompasses the rule of law, individual rights, and the provision of regulation and public services; its deterioration undermines the institutional framework for development.
Saeed (2022) [75]	Defines institutional quality by the degree to which a country is "grabber-friendly" (extractive) or "producer-friendly" (productive): the former facilitates rent capture; the latter promotes transparent use of resources.

As Figure 2 shows, trustworthy institutions, robust financial markets, and sustainability goals such as the clean energy transition, reinforce each other because good rules reduce regulatory risk and attract capital; abundant, cheap financing accelerates the adoption of clean technologies; and social demand for sustainability legitimizes and consolidates institutional and financial reforms.

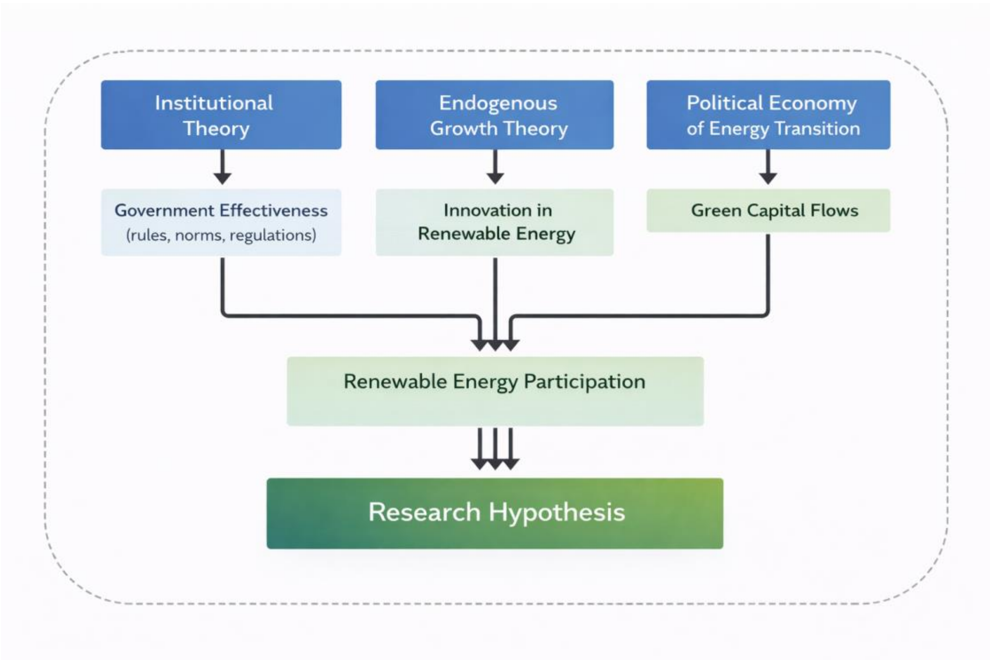

Figure 2. Study's conceptual map.

2.2. Data sources

The research examines 16 Latin American countries, including Argentina, Bolivia, Brazil, Chile, Colombia, Costa Rica, Ecuador, Guatemala, Mexico, Paraguay, Peru, Honduras, Nicaragua, El Salvador, Panama, and Venezuela, to study regional power generation capacity. The observation period runs from 2002 to 2021; the first years mark the entry into force of the Kyoto Protocol, and the last incorporate the first waves of sovereign green bonds following the Paris Agreement. The analysis used 320 observations (16 countries × 20 years) after removing all missing data points. The profile of each country is described in greater detail in Appendix A1. The area contains equatorial rainforests, subtropical savannahs, high-altitude plateaus, and temperate pampas, which create a unique combination of hydrological, solar, and wind resources [76,77]. Data from the Economic Commission for Latin America and the Caribbean (ECLAC) indicates that, in 2021, its population reached 666 million inhabitants, with a median gross domestic product (GDP) per capita of USD 15,084 [78]. Despite recording the highest global share of renewable electricity, at 62 % in 2022, the matrix relies heavily on aging hydropower (more than 45% of generation) that is increasingly exposed to climate-induced hydrological variability [79]. The growth rate of modern renewables, including solar power, wind energy, and bioenergy, reached 25% during 2015–2025, yet these technologies need at least USD 150 billion in annual funding to reach Paris Agreement targets [80,81]. Socioeconomic heterogeneity is considerable: climate readiness as measured by the ND-GAIN readiness index ranges from 0.28 in Bolivia to 0.71 in Chile [82].

2.2.1. Variable construction

With this in mind, and given the availability and comparability of data for the sample, the dependent variable is defined as the share of renewable energy in total final energy consumption (renewable), using World Bank data. This indicator was selected because it is widely used to measure renewable energy penetration at the macroeconomic level, encompassing both electricity generation and end-uses. This, in turn, facilitates the comparison of energy transition trajectories across countries with diverse productive structures while maintaining consistent time- series data. Its calculation considers energy generated from renewable sources (hydroelectric, wind, solar, biomass, geothermal, and ocean) as a proportion of total energy derived from all sources, including fossil fuels, nuclear energy, and renewables.

To estimate and address hypothesis 1 regarding direct effects, two relevant variables from the study are taken into consideration: government effectiveness (gov_eff), a sub-component of the Worldwide Governance Indicators (WGI) measured by the World Bank, and the IMF's financial development index. The government effectiveness indicator captures perceptions regarding the quality of public services, the civil service and its independence from political pressures, the quality of policy formulation and implementation, and the credibility of the government's commitment to such policies [83]. The financial development index, meanwhile, allows us to examine two main pillars as a robust composite measure: financial institutions (FI) and financial markets (FM). Each of these pillars is further disaggregated into three dimensions: depth, access, and efficiency. In the case of financial institutions, "depth" encompasses indicators of size as well as banking and non-banking intermediation (e.g., credit to the private sector or assets held by funds and insurance companies); "access" serves as a proxy for the financial system's reach among households and firms; and "efficiency" reflects the costs and performance of financial intermediation. In the context of financial markets, depth measures market size (such as market capitalization or issued debt), access reflects the breadth of participation and issuance, and efficiency is associated with liquidity and the capacity to allocate capital effectively [84]. Following the logical line of the second hypothesis: Given that investments in renewable energy are capital-intensive, require long-term horizons, and are exposed to regulatory risk, the effect of financial development (FD) on renewable energy adoption is not expected to be uniform, as the literature review has already made clear. Rather, it is assumed that this effect depends on the institutional environment. Therefore, the econometric specification includes interaction terms that allow the marginal effect of financial development to vary across two distinct institutional dimensions. The interaction with climate readiness (fin × read) is grounded in the idea that greater readiness capacity reduces investment frictions, uncertainty, and transaction costs, thereby increasing the likelihood that greater financial depth will translate into the effective deployment of renewable energy. Secondly, the interaction with government effectiveness (fin × gov) acknowledges that the energy transition relies on permitting processes, energy market regulation, tariff standards, grid planning, and the credibility of public commitments. Based on these mechanisms, both terms (fin × read and fin × gov) are included to capture specific marginal effects: (i) that the financial system drives renewable energy adoption primarily when there is sufficient investment absorption capacity, or climate readiness in place; and (ii) that the State's implementation capacity can either amplify or constrain the effect of the financial channel by influencing the stability and enforceability of the regulations underpinning long-term green investments. The simultaneous inclusion of both interaction terms allows us to distinguish whether the enabling environment that "greens" finance is driven more by absorption capacity (read) or by general state capacity (gov), thereby avoiding the misattribution of an effect to one dimension that actually belongs to the other. In this context, the fact that an interaction is not significant does not invalidate its inclusion; on the contrary, it provides evidence of which institutional dimension effectively conditions the financial channel in Latin America. Additionally, complementary variables are incorporated to help articulate and enhance the interpretation of the results for the variables analyzed in this study: namely, climate readiness, measured through the ND-GAIN Readiness sub-index (read). This indicator assesses a country's capacity to mobilize and absorb investments, and to transform them into concrete transition actions. Its measurement encompasses three dimensions: (i) economic opportunity, related to the robustness of the economy and a business environment that facilitates the channeling of resources toward vulnerable sectors; (ii) governance, linked to political stability, security, and low levels of corruption, factors that reduce investment risks, particularly for international investment; and (iii) social structures, which include human capital, the rule of law, and access to information and communication technologies, elements that enhance the viability of investment projects [85]. For its part, the per capita ecological footprint (ecol_fp) is a widely used measure of environmental pressure employed to diagnose the extent to which human activities exert pressure on available natural resources. To this end, Table 4 describes the five types of biologically productive land that comprise this variable: cropland, forest areas (including the carbon component necessary to absorb CO_2), grazing land, fishing grounds, and built-up areas [86].

Once all variables were explained and before proceeding with the econometric analysis, the shape and dispersion of each series were explored using violin plots (Figure 3). This representation combines kernel density estimation with the interquartile range, enabling the detection of pronounced asymmetries and outliers.

Table 4. Variables operationalization.

Construct	Operational variable	Abbreviation	source
Renewable energy adoption (dependent)	Share of renewables in total final energy consumption	Ren	World Bank
Climate readiness	ND-GAIN readiness score	Read	ND-GAIN Country Index (Notre Dame Global Adaptation Initiative)
Government effectiveness	WGI-government effectiveness	Gov_eff	World Bank
Financial development	Financial development index	Fin_index	International Monetary Fund
Environmental pressure	Ecological Footprint Per Capita	Ecol_fp	Global Footprint Network
FD-climate readiness		Inter_fin_read	
FD-governance		Inter_fin_gov	

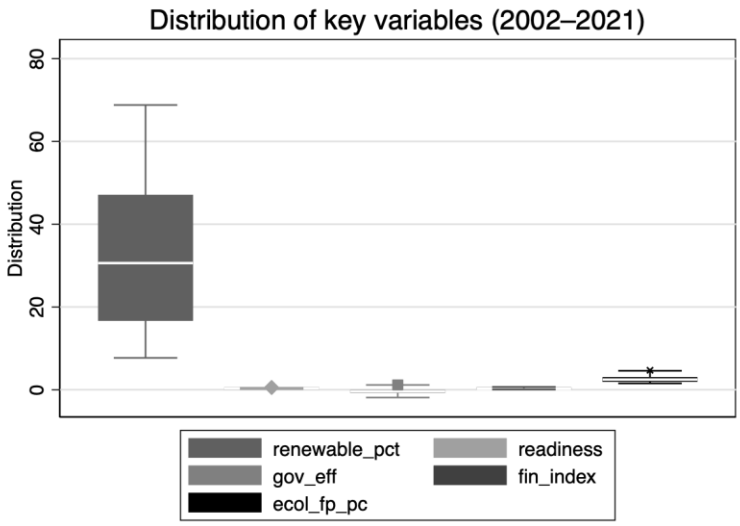

Figure 3. Distribution of key variables.

Figure 3 illustrates the significant economic disparities among Latin American nations through their energy systems, institutional frameworks, and financial structures, spanning the period from 2002 to 2021. The share of renewable energy exhibits the greatest variation, with nations generating up to 62% of their electricity from clean sources, an indication that hydroelectric power (which accounted for 45% of generation) coexists alongside fossil-fuel-based generation systems. Indicators for climate readiness and government effectiveness follow a distribution pattern that places the majority of countries near the global average, though several nations experience regulatory delays in adopting frameworks that support the energy transition. The financial index reveals relatively underdeveloped and fairly homogeneous markets; only a few economies, specifically those with the highest banking intensity or development, deviate slightly from this general pattern. Furthermore, the ecological footprint shows a moderate range in this analysis, with the highest values correlating with lower percentages of renewable energy. Proceed to standardize using the simple standardization equation:

$$Z_i = \frac{(x_i - \bar{x})}{\sigma} \quad (1)$$

to facilitate the interpretation of the coefficients. Interaction terms inter_fin_read and inter_fin_gov are generated as products of the standardized variables. Screening retained only those countries with complete observations for every variable, producing a balanced panel of 16 countries and 20 years in total, making 320 observations (after excluding rows with missing values).

2.2.2. Methodology

The core specification is a two-way fixed-effects (FE) model estimated with Driscoll–Kraay heteroskedasticity-consistent standard errors. This approach is particularly appropriate for the panel structure used in this study, as the data track multiple countries over time and are therefore susceptible to several econometric issues that may compromise conventional inference. In particular, the error structure may exhibit heteroskedasticity, serial correlation, and cross-sectional dependence across units, even when such dependence reflects common shocks or shared regional dynamics [87,88]. Within the empirical literature on Latin America, studies on finance and growth have more commonly relied on estimators such as FE-IV, GMM, or conventional fixed-effects models, rather than procedures that explicitly address cross-sectional dependence. Accordingly, the use of the Driscoll–Kraay estimator may be regarded as methodologically less common, though by no means unprecedented [89,90]. Its application is especially relevant in a regional context such as Latin America, where countries are frequently exposed to common macroeconomic disturbances and policy spillovers. In this respect, the estimator helps reduce the risk of drawing overly optimistic conclusions regarding the statistical significance of the financial system or broader regional influences [91].

Moreover, because the Driscoll–Kraay variance-covariance matrix belongs to the family of heteroskedasticity- and autocorrelation-consistent (HAC) estimators, its implementation requires the specification of a truncation parameter, or bandwidth, that determines the number of lagged autocovariances used in the computation of standard errors [92]. For this reason, prior to selecting the bandwidth, serial dependence was examined using the Cumby–Huizinga test, which is particularly well suited to settings characterized by heteroskedasticity and the possible presence of endogenous regressors [93]. This strategy avoids relying exclusively on automatic bandwidth-selection rules. In empirical practice, such rules typically depend on functions that increase with T, including the common rule of thumb based on T^⅓ [93], or on automated procedures such as those proposed by Newey and West [94]. The results indicate statistically significant evidence of autocorrelation up to the second order, whereas higher-order lags do not display a consistent pattern. Based on this diagnostic, a Driscoll–Kraay bandwidth with lag = 2 is retained as the baseline specification.

At the same time, the empirical strategy acknowledges the possibility of endogeneity. In this setting, this issue may arise from reverse causality or from omitted time-varying factors that affect both renewable energy adoption and the key explanatory variables. Although the two-way fixed-effects structure helps mitigate part of this concern by controlling for time-invariant country heterogeneity and common year-specific shocks, it does not fully eliminate endogeneity. The estimates should therefore be interpreted as robust conditional associations rather than as strict causal effects. In principle, an instrumental-variable or quasi-experimental strategy could strengthen identification. However, given the study's regional cross-country design and the difficulty of identifying valid, theoretically defensible instruments for the main regressors, the analysis adopts a deliberately conservative panel-data strategy based on fixed effects, robust inference, and sensitivity analysis.

Table 5 reports statistically significant autocorrelation up to the third lag ($\chi^2 = 133.4$; $p < 0.01$). Accordingly, the lag = 3 specification is presented as an explicit robustness check, whereas lag = 2 is retained as the baseline Driscoll–Kraay bandwidth on grounds of parsimony. The stability of the main results across both specifications provides additional support for the robustness of the empirical findings.

Table 5. Cumby–Huizinga autocorrelation test (model residuals with country-year dummies).

Range of lags	χ^2	gl	p-value
1–1	133,390	1	**0,0000**
1–2	133,398	2	**0,0000**
1–3	133,414	3	**0,0000**

2.2.3. Econometric specification

Let i be the country and t be the year. The fixed-effects model with Driscoll–Kraay errors was estimated according to the equation:

$$Ren_{i,t} = \alpha_i + \beta_1 Read_{i,t} + \beta_2 Gov\_eff_{i,t} + \beta_3 Ecol\_fp_{i,t} + \beta_4 Fin\_index_{i,t} + \beta_5 interfin\_read_{i,t} + \beta_6 interfin\_gov_{i,t} + \mu_i + \lambda_t + \varepsilon_{i,t} \quad (2)$$

where ren is the dependent variable representing the percentage of renewable energy within the total energy consumption of country i in year t; gov_eff measures the Government's capacity to implement effective policies; and Fin-Index reflects the robustness and development of the Financial System. inter_fin_read and inter_fin_gov function as interaction variables that capture effects not observed in the direct effects. Additionally, ecol_fp acts as a proxy variable for the per capita ecological footprint, linked to the unsustainable use of natural resources, while read is a sub-component of the ND-GAIN index related to each country's climate readiness, which also includes a country-specific fixed effect (unobservable heterogeneity), a time-specific effect common to all countries (aggregate shocks), and, an error term.

2.2.3.1. Robustness checks and time partitioning

Robustness checks include: (i) sub-period estimations for 2002–2014 (pre-Paris), corresponding to the period prior to the Paris Agreement, characterized by policies less oriented toward renewable energy and a nascent green bond market, and for 2015–2021 (post-Paris), marking the period of national decarbonization commitments and massive inflows of external climate capital; (ii) alternative lag structures (lag = 3); and (iii) a re-estimation excluding outliers dominated by hydroelectric power—such as the case of Paraguay (see Appendix A3), in order to assess sensitivity to structural dependence on large hydroelectric dams.

As an additional analysis, threshold-sensitive marginal effects mapping, or "visual thresholding", is introduced to visualize how the conditional effect of fin_index on renewable_pct evolves across the continuous distribution of the readiness level. This approach, employed by Bauer, applies the delta method to derive Johnson-Neyman confidence bands and identifies the readiness value (≈ +1 to +2 SD) at which the financial coefficient changes sign [95]. This diagnostic refines previous dichotomous "high/low" governance classifications by providing precise inflection points, thereby offering a policy-relevant threshold for sequencing institutional and financial reforms. This analysis is presented in Appendix A2, and its results are referenced throughout this study.

3. Results

3.1. Descriptive statistics

Descriptive statistics and Pearson correlations are used to diagnose central tendency, dispersion, and bivariate associations, following Wooldridge's guidelines for panel data diagnostics [96]. Table 6 summarizes the definition and origin of each series, as well as their basic statistics for the balanced panel 2002–2021, as follows:

Table 6. Variable's descriptive statistics.

Variable	Mean	Std Dev	Mín	Máx
Ren	32,9 %	17,7	7,7	68,8
Read	–0,31	0,09	–1,60	0,57
Gov_eff	–0,35	0,57	–1,89	1,19
Fin_index	–0,28	1,35	–0,68	0,67
Ecol_fp	2,56	0,72	1,54	4,69

The data in Table 6 show that Latin America achieved a regional average of 33% renewable-sourced energy, a figure that exceeds the global average of 30% over the 2002–2021 period [97]. The pace of the transition varies across systems, as their use of renewable energy ranges from 7.7% to 68.8%. Institutional quality is modest, albeit gradually improving, as both indicators, climate readiness (read) and government effectiveness (gov_eff), yield negative averages, indicating that the region still falls short of the global benchmark. Scores for government effectiveness (SD = 0.57) reveal that while some countries position themselves as performance leaders, others face considerable difficulties.

Secondly, financial development is modest and highly heterogeneous. The composite index fluctuates between −0.68 and 0.67 standard deviations; no country attains a high level by international standards, which explains why green capital does not flow with the intensity observed in Asia or the European Union. The high standard deviation (1.35) suggests significant scope for implementing financial inclusion policies and expanding capital markets. Meanwhile, environmental pressure, measured by the per capita ecological footprint, doubles between the lowest and highest percentiles, highlighting the latent environmental pressures in certain export-oriented economies. The inclusion of this factor in the regression models helps to avoid attributing outcomes to the financial or institutional spheres that, in reality, stem from differences in consumption patterns.

Table 7 shows a pattern of correlations that reinforces the hypothesis that financial-institutional dynamics are a prerequisite, but not a guarantee, for accelerating the energy transition in Latin America:

Table 7. Variable's correlation table.

	Renewable	Readiness	Gov_eff	Fin_index	Ecol_fp
Ren	1	**−0,221**	−0,090	**−0,238**	**−0,342**
Read		1	**0,658**	**0,639**	**0,533**
Gov_eff			1	**0,518**	0,262
Fin_index				1	**0,473**
Ecol_fp					1

(n = 320; |ρ| > 0.10 in bold)

The two primary explanatory variables, along with the complementary ones, exhibit relationships ranging from negative to moderate with the percentage of renewable electricity, reflected in the following values: –0.24 for financial development, –0.09 for government effectiveness, –0.34 for ecological footprint, and –0.22 for climate readiness. The data indicate that countries reliant on fossil fuels tend to develop larger-scale financial systems but simultaneously face mounting environmental challenges. The low correlation with government effectiveness (gov_eff) suggests that administrative and regulatory capacity, in and of itself, does not lead to increased renewable energy usage, even in the absence of specific policies. The study identifies three primary institutional-financial factors that account for these results: climate readiness and government effectiveness (0.66), readiness and financial development (0.64), and, once again, government effectiveness in relation to finance (0.52). These factors are justified when regulatory frameworks are predictable, and the executive branch operates efficiently. The financial sector evolves through expansion and diversification, thereby creating an optimal environment for the application of green financial instruments. Furthermore, the research reveals a positive correlation between financial development and the ecological footprint, with a value of 0.47; this suggests that developed markets, which anchor their economic growth in high levels of per capita consumption, actively link their expansion to climate protection, recognizing that failure to do so would result in adverse environmental impacts.

In conclusion, the correlation matrix reveals a distinct scenario within the region, characterized by a "co-evolutionary triangle" (governance ↔ finance ↔ readiness) that ultimately determines the impact of green investment on the energy matrix. Without coordinated improvements across these three axes, the mere availability of capital does not translate into a significant penetration of renewable energy sources. Consequently, this relationship warrants further validation through the main model and subsequent robustness checks.

3.2. Direct effects

Table 8 shows the main results of the fixed effects model, with Driscoll–Kraay errors with lag = 2 for the full sample standardized.

Table 8. Main results with lag = 2.

Variable	Coefficient	SD	t	P > |t|	95% CI Lower	95% CI Upper
Read	−0.1067294	0.0346494	−3.08	0.006	−0.1792515	−0.0342073
Gov_eff	0.0251881	0.0175387	1.44	0.167	−0.0115208	0.0618897
Fin_index	−0.1352445	0.0460341	−2.94	0.008	−0.2315949	−0.038894
Ecol_fp	−0.2264622	0.0541515	−4.18	0.001	−0.3398026	−0.1131217
Inter_fin_read	0.0951361	0.0296536	3.21	0.005	0.0330785	0.1572017
Inter_fin_gov	−0.0284532	0.0204298	−1.39	0.18	−0.0712132	0.0143069
Cons	−0.0458523	0.0167128	−2.74	0.013	−0.0808326	−0.0108721

The model demonstrates a robust fit, given that the F-value reaches 107.45, and the p-value is less than 0.001, while the within R^2 value (within countries) equals 0.39, indicating that the primary and complementary variables included in the main econometric model capture nearly 40% of the internal variation within each country over time.

Regarding financial development (fin_index), it exhibits a negative coefficient ($\beta = -0.135$; $p = 0.008$); that is, more developed financial markets do not, in themselves, guarantee greater renewable energy penetration if the underlying institutional quality (gov_eff) is low or moderate. However, the moderating effect of the financial development × climate readiness interaction ($\beta = 0.095$; $p = 0.005$) reverses the previous conclusion by demonstrating that the influence of finance becomes positive as readiness surpasses the regional average (the estimated crossover point of +1.1 SD coincides with the threshold value). In itself, climate readiness (read) shows a negative and statistically significant effect ($\beta = -0.107$; $p = 0.006$). The results reveal that nations with more prepared transition systems maintain their reliance on large-scale conventional hydroelectric plants, thereby reducing their share of modern renewable energy sources after data standardization. With respect to government effectiveness (gov_eff), it exerts a non-significant direct effect ($\beta = 0.025$; $p = 0.17$); likewise, its interaction with finance (inter_fin_gov) also fails to reach significance at the 10% level ($\beta = -0.028$; $p = 0.18$). Finally, the ecological footprint (ecol_fp) maintains the expected negative relationship ($\beta = -0.226$; $p = 0.001$): countries facing greater environmental pressures rely less on modern renewable energy sources, thereby confirming the relevance of monitoring. Consequently, this initial approach yields an important result: taken together, the coefficients confirm that financial development drives decarbonization only when supported by other conditioning factors; the results indicate that preparedness acts as the primary factor enabling the successful mobilization of financing across the region, superseding conventional regulatory capacities.

3.3. Robustness tests

The following table shows the results by subgroup for the moderating effects and as part of the robustness test of the study:

Table 9. Results for the 2002–2014 sub-period (208 observations; 16 countries).

Variable	Coefficient	Std. Dev.	t	P > |t|	95% CI Lower	95% CI Upper
Read	−0.0959437	0.0318445	−3.01	0.011	−0.1653271	−0.0265604
Gov_eff	0.0144369	0.0194964	0.74	0.473	−0.0208421	0.0569516
Fin_index	−0.1467201	0.0320848	−4.58	0.001	−0.2164526	−0.0769877
Ecol_fp	−0.1373307	0.0263086	−5.22	0	−0.1946522	−0.0800091
Inter_fin_read	0.0915314	0.0181865	5.03	0	0.0519055	0.1311563
Inter_fin_gov	−0.0109066	0.0171052	−0.64	0.536	−0.0481756	0.0263624
Cons	−0.0436115	0.0166516	−2.62	0.022	−0.0798922	−0.0073309

The fixed-effects model with Driscoll–Kraay errors (lag = 2) maintains a significant fit ($F = 76.99$; $p < 0.001$; R^2 within = 0.325), confirming that the predictors explain approximately one-third of the within-country variation in the share of renewable energy.

The climate readiness factor ($\beta = -0.096$; $p = 0.011$) retains its negative relationship with the data: countries with well-developed regulatory systems during the pre-Paris Agreement era maintained their reliance on large-scale hydroelectric facilities, resulting in lower adoption of modern renewable energy sources following standardization. Financial development ($\beta = -0.147$; $p < 0.001$) also exhibits a more pronounced negative coefficient compared to the full sample, indicating that, prior to 2015, the financial sector did not systematically channel resources toward projects relevant to the energy transition. Furthermore, the finance × readiness interaction demonstrates a significant positive relationship ($\beta = 0.092$; $p < 0.000$), with financial influence becoming statistically significant when readiness exceeds 1.1 standard deviations (SD). Consequently, this study confirms the existence of a threshold during the initial stage of the sustainable debt market's development.

The analysis reveals that governance effectiveness ($\beta = 0.014$; $p = 0.473$) and its interaction with finance ($\beta = -0.011$; $p = 0.536$) are not statistically significant. The first decade of the analysis demonstrated that administrative and regulatory efficacy, on its own, did not drive the growth of green investment; furthermore, the complementary analysis of the ecological footprint ($\beta = -0.138$; $p < 0.000$) maintained its negative relationship with respect to changes in the proportion of clean energy sources in those countries exhibiting higher environmental pressure. The expansion of renewable energy in Latin America between 2002 and 2014 required institutions endowed with robust frameworks, as well as financial systems capable of maximizing the effectiveness of such incentive programs. In cases where regulatory quality fell below a certain threshold, financial deepening was counter-intuitively associated with a lower share of renewable energy; this reflects the priority markets assigned to channeling capital into conventional projects, which were perceived as lower risk. Consequently, these results justify the subsequent inclusion in the discussion section of policies that combine regulatory reforms with sustainable finance tools to align capital supply with regional decarbonization objectives.

Table 10 presents the results for the post-Paris Agreement period. The fixed effects model with Driscoll–Kraay standard errors (lag = 2) maintains strong explanatory power ($F = 165.9$; $p < 0.001$; within $R^2 = 0.438$). However, the key coefficients exhibit different nuances compared to those observed in the previous period:

Table 10. Interpretation of coefficients for the 2015–2021 sub-period.

Variable	Coef.	Std. Dev.	t	p-value
Read	–0,085	0,079	–1,1	0,321
Fin_index	–0,007	0,144	–0,05	0,965
Ecol_fp	–0,410	0,113	–3,64	0,011
Inter_fin_read	–0,019	0,046	–2.18	0,698
Gov_eff	–0,084	0,067	–1.26	0,255
Inter_fin_gov	–0,019	0,046	0,41	0,747

The region underwent a complete transformation after 2015, as institutions now support renewable energy; however, financial growth has not led to direct funding for green initiatives. The absence of a significant interplay between financial development and climate readiness confirms that nascent sustainable bond markets are currently in a learning phase: they remain insufficient to fully leverage improved regulatory frameworks. The ecological footprint reveals a significant negative impact, as countries with high environmental demands are failing to make sufficient progress in their transition toward sustainability, precisely as discussed in the introduction to this article.

Furthermore, Latin America possesses institutions well-suited for the post-Paris Agreement era; however, it requires specific financial instruments, established market incentives, and investment-ready projects to generate financial growth that drives reductions in carbon emissions [98]. The discussion section, will present the following recommendations: aligning existing regulations through public support mechanisms and measures to activate the financial channel, which, as the model demonstrates, indeed exists but remains unproductive. Below, we highlight the results for key variables across different periods, emphasizing the changes observed between the various time-frames in the table presented here:

Table 11. Comparisons of coefficients between periods.

Variable (z)	(1) 2002–2021	(2) 2002–2014	(3) 2015–2021
Climate readiness	–0,107 *** (0,035)	–0,096 ** (0,032)	–0,085 (0,079)
Government effectiveness	0,025 (0,018)	0,014 (0,019)	–0,084 (0,067)
Financial index	–0,135 *** (0,046)	–0,147 *** (0,032)	–0,007 (0,144)
Ecological footprint	–0,226 *** (0,054)	–0,137 *** (0,026)	–0,410 *** (0,113)
Inter_fin_read	0,095 *** (0,030)	0,092 *** (0,018)	–0,019 * (0,046)
Inter_fin_ gov	–0,028 (0,020)	–0,011 (0,017)	0,019 (0,046)
Constant	–0,046 ** (0,017)	–0,044 ** (0,017)	–0,025 (0,073)
Observations	320	208	112
R^2 within	0,393	0,325	0,438

Note: *p < 0.1, **p < 0.05, ***p < 0.01

Across the entire sample (Col. 1) and during the pre-2015 period (Col. 2), a one-standard-deviation (SD) increase in the climate readiness index reduces the share of renewable energy by 9 to 11 percentage points (p.p.). This suggests that, prior to the Paris Agreement, countries with emerging regulatory frameworks had greater scope to expand in the renewable energy sector through specifically designed policies (particularly for hydroelectric power). After 2015 (Col. 3), the coefficient becomes statistically insignificant, indicating that most regulatory systems have established a minimum standard; consequently, the transition process is now driven by other financial and technological mechanisms. Financial development exhibits a negative and significant effect prior to 2015 (−0.15 p.p. SD). This confirms that, in unstable institutional environments, resources are channeled toward established traditional sectors that offer secure investments with rapid returns. The statistical relationship between green bonds and syndicated loans becomes insignificant after 2015, demonstrating that these financial instruments have not yet reached a sufficient volume to generate perceptible positive effects. Additionally, the ecological footprint's adverse impact is significant across all models and intensifies in the post-Paris Agreement era. The environmental conditions of individual nations determine their capacity to transition away from fossil fuels and hydroelectric power, as countries under high environmental stress face limited opportunities to adopt new energy systems.

Regarding the interaction terms, prior to 2015, the term fin × readiness was positive and highly significant: financial depth offsets the negative bias when readiness exceeds the identified threshold (+1.1 SD). In the 2015–2021 period, the sign reverses (−0.019; $p < 0.10$). This can be interpreted in two ways: first, that a portion of green capital is channeled toward countries that have already reached an advanced stage of development, thereby reducing the marginal effect; and second, that the small sample size of projects in markets already possessing the necessary readiness limits the statistical power of the analysis. The second interaction, pertaining to government effectiveness, shows no impact whatsoever, indicating that greater administrative and regulatory efficiency does not affect how financing responds to the transition process. The final subsample (post-agreement) exhibits the highest explained variance ($R^2 = 0.438$), given that it contains less macroeconomic "noise" and reflects more coherent sustainability policies following the signing of the Paris Agreement. Nevertheless, key coefficients indicate that it is necessary to intensify the use of financial instruments specifically geared toward sustainability, such as green bonds and other available instruments, to unlock the full potential already offered by the most well-established institutions.

Ultimately, this comparative table reveals a temporal decoupling: institutional improvement succeeded in neutralizing structural barriers, it has not yet been accompanied by a critical mass of green financial instruments capable of translating into statistically robust increases in the share of renewable energy after 2015. For the region, the next step involves not merely increased regulation, but also extending maturity periods, reducing the cost of green capital, and standardizing risks, so that financial development ceases to be neutral and instead becomes a direct driver of decarbonization. Continue with the robustness check, Table 12 shows the fixed-effects regression with Driscoll–Kraay errors after extending the recall window to three lags. Key parameters remain stable, reinforcing the main narrative:

Table 12. Interpretation of coefficients with Lag = 3.

Variable	β	Std. Dev	t	Signif.
Read	−0,095	0,030	−3,22	0,005
Fin_index	−0,136	0,045	−2,98	0,008
Inter_fin_read	0,074	0,018	4,05	0,001
Gov_eff	0,012	0,013	0,89	0,386
Ecol_fp	−0,227	0,054	−4,21	< 0,001
Cons	−0,047	0,018	−2,56	0,019

The Cumby–Huizinga test identifies serial correlation up to the third lag. Accordingly, the model with lag = 3 is reported as an explicit robustness check. At the same time, lag = 2 is retained as the baseline specification on grounds of parsimony, since the substantive results remain stable under both bandwidth choices. The comparison between Tables 8 and 12 confirms this stability. In particular, the direct effect of financial development is virtually unchanged ($\beta = -0.135$, $p = 0.008$ under lag = 2; $\beta = -0.136$, $p = 0.008$ under lag = 3), and the key interaction term, fin × read, remains positive and statistically significant in both specifications ($\beta = 0.095$, $p = 0.005$; $\beta = 0.074$, $p = 0.001$, respectively). Thus, extending the Driscoll–Kraay bandwidth from 2 to 3 only modestly reduces the magnitude of the interaction term, without altering its sign, statistical significance, or substantive interpretation. Even under the more conservative lag = 3 specification, the results continue to support the same core mechanism: financial development contributes to the energy transition only when it operates alongside sufficient climate readiness. Below the estimated threshold of +1.1 SD, the marginal effect of finance remains adverse; above that point, it becomes positive and statistically robust. This pattern reinforces the interpretation that financial deepening alone is insufficient to accelerate renewable energy adoption unless it is accompanied by enabling institutional and absorptive conditions. From a policy perspective, the evidence therefore supports integrated reform packages that combine financial instruments such as green bonds, development banking, and blended finance with measures to improve regulatory predictability, coordination, and project-execution capacity. More broadly, the stability of this threshold pattern across both lag structures aligns the Latin American evidence with the international literature identifying institutional thresholds in the range of +1 to +2 SD. Finally, Table 13 reinforces the results by applying the model while excluding the most hydro-dependent case in the sample, which is Paraguay (see Appendix 3).

Table 13. Synthetic interpretation of the regression with Driscoll–Kraay Errors (300 observations, 15 countries, 2002–2021; lags = 2).

Variable	Coefficient	Std.Dev.	t	P > |t|	95% CI Lower	95% CI Upper
Read	−0.0368128	0.0233515	−1.58	0.131	−0.085688	0.0120625
Fin_index	−0.1103918	0.0538724	−2.05	0.055	−0.2231481	0.0023645
Inter_fin_read	0.0437883	0.0192281	2.28	0.035	0.003536	0.0840257
Gov_eff	0.0196585	0.0173818	1.13	0.272	−0.0167219	0.056639
Ecol_fp	−0.2831516	0.0685638	−4.16	0.001	−0.4286573	−0.1416459
Cons	−0.1487207	0.0215507	−6.9	0	−0.1938268	−0.1036146

Upon excluding Paraguay, whose energy matrix is almost entirely hydroelectric and could skew regional averages, the core coefficients once again confirm the central narrative: financial system lacking sufficient governance continue to act as a drag, as indicated by the fin_index coefficient (−0.11; p = 0.055). This coefficient demonstrates that the mere expansion of capital remains associated with a lower share of renewable energy when readiness falls below the established threshold. The interaction term retains both its sign and its statistical significance; a positive slope of 0.044 indicates that, beyond +1.1 SD in the level of climate readiness, each additional deviation in the financial index increases the share of renewable energy by approximately 0.04 p.p. This finding replicates the pattern observed in the full sample, demonstrating that said pattern was not dependent on the outlier case of Paraguay. In contrast, the ecological footprint yields negative results that become more pronounced (−0.28; p < 0.01), suggesting that countries that have previously degraded their environments lag behind in implementing modern renewable energy technologies.

Recap, the exclusion of Paraguay does not alter the fundamental conclusion drawn throughout this experiment: financing becomes a significant driver of the energy transition in Latin America only when it converges with robust economic, social, and institutional frameworks. This test supports the external validity of the results and reinforces the recommendation to integrate financial deepening and development with effective planning for renewable energy investments.

4. Discussion

The results of this study demonstrate that the relationship between financial development and the energy transition in latin america is not automatic, but rather conditional and nonlinear [99]. in the full panel for the period 2002–2021, financial development exhibits a negative direct effect on the share of renewable energy (β ≈ −0.135; p = 0.008), whereas government effectiveness shows no statistically significant direct effect (β = 0.025; p = 0.17). By contrast, the interaction between financial development and climate readiness is positive and significant (β ≈ 0.095; p = 0.005), suggesting a threshold effect: financial deepening drives the expansion of renewable energy only when climate preparedness exceeds approximately +1.1 SD. In substantive terms, this indicates that deeper financial markets do not, on their own, guarantee a greener allocation of capital. For finance to truly drive the energy transition, institutional and operational conditions must be in place to enable the absorption, channeling, and execution of investments in renewable technologies. This result is consistent with previous studies regarding the role of other conditioning factors in activating the financial channel, such as Olaniyi's work on the threshold in the relationship between finance and governance in african countries [100], as well as Arcand's work on the link between financial development and economic development [101].

These findings are best interpreted through a combined lens of institutional economics, endogenous growth theory, and the political economy of the energy transition. From an institutional perspective, the results support the notion that investment outcomes depend on the credibility, predictability, and coordination capacity of the rules that structure economic exchange. From the perspective of endogenous growth theory, they confirm that finance can act as an engine of structural transformation, though not in a linear or automatic fashion. A political economy perspective is particularly useful for explaining why this effect remains conditional in Latin America: when institutional readiness is insufficient, financial deepening may continue to favor established, conventional, lower-risk sectors rather than renewable technologies. In this sense, the study does not reject the broader literature linking finance and institutions to the energy transition; rather, it refines it by demonstrating that, in the Latin American context, the financial channel is activated only when the enabling environment is robust enough to overcome regulatory uncertainty, implementation constraints, and the inertia of existing energy structures.

This interpretation becomes especially relevant when considering the estimated threshold of approximately +1.1 SD. That value should not be interpreted as a mechanical cutoff point for public policy, but rather as an econometric inflection point with substantive institutional content. In this study, climate readiness is not merely an abstract control variable; rather, it reflects a country's capacity to mobilize investment and translate it into effective action through its economic, institutional, and social readiness. From this perspective, it is unlikely that this threshold is a mere statistical artifact. Instead, it appears to encapsulate the point at which the institutional environment becomes sufficiently credible and possesses sufficient absorptive capacity for finance to operate in a "green" direction. Below this level, deeper financial markets still tend to reinforce conventional investment patterns, favoring sectors characterized by more familiar technologies, lower transaction costs, and faster or more predictable returns. Above this point, conversely, the investment environment becomes sufficiently stable and coordinated to support the deployment of renewable energy through financial depth. In practical terms, this crossover likely reflects the combined presence of more predictable regulatory frameworks, enhanced planning capacity, reduced execution risk, improved institutional coordination, and a more bankable project pipeline. This interpretation also helps explain why countries in the sample with relatively higher levels of readiness, such as Chile and Costa Rica [102,103], serve as useful illustrative cases: not because they mechanically define the threshold, but because they represent environments where policy continuity, implementation capacity, and investment conditions are more developed than the regional average (see Appendix 4). Thus, the threshold of +1.1 SD should be understood less as a statistical curiosity and more as a condensed empirical expression of the point at which readiness becomes sufficient for finance to cease acting as a neutral or adverse force and begin functioning as a lever for decarbonization.

Against this background, four consistent results emerge from the analysis. First, the negative coefficient for financial development remains stable across the main specifications and robustness checks. This implies that when institutional conditions are weak or merely average, greater financial deepening tends to favor established sectors, which present lower risk and offer more predictable returns. Renewable energy projects, by contrast, require substantial upfront investments, longer development horizons, and reliable regulatory frameworks. The work of Badmus and Bisiruyu also supports this interpretation [104]. Consequently, the results do not support hypothesis 1. Finance, in and of itself, does not exert a direct positive effect on the share of renewable energy. Rather than contradicting the literature on finance and productive transformation, this result refines it by suggesting that, within the Latin American energy context, financial development unaccompanied by sufficiently robust enabling conditions may reinforce incumbent sectors rather than accelerate technological change.

Second, the interaction between financial development and climate readiness emerges as the most significant conditional channel in the analysis. Its positive sign, its persistence across the full panel, the pre-2015 sub-period, and the robustness checks reinforce the interpretation that the financial system accelerates the energy transition only when a sufficiently enabling environment is in place. This notion is further supported by other studies, such as that of González, who argues that the financial system drives the energy transition only when institutional conditions genuinely facilitate such investment [49]. This implies that climate preparedness functions not merely as an additional control variable, but as a prerequisite that renders financial development "operative" for the energy transition. In this regard, the findings confirm and build upon previous empirical work by demonstrating with greater clarity that the financial channel in Latin America becomes active only once a measurable threshold is surpassed, and does not operate uniformly across countries.

Third, the per capita ecological footprint shows a negative, statistically significant association with the share of renewable energy. This result suggests that more resource-intensive consumption patterns and greater environmental pressures tend to hinder the advancement of renewable energy, even when controlling for financial and institutional factors. Therefore, the energy transition depends not solely on expanding the supply of financing, but also on transforming the productive structures and consumption patterns that continue to reproduce high levels of environmental pressure.

A fourth finding of particular relevance is the lack of statistical significance for government effectiveness, both in its direct effect and in its interaction with finance. This result takes on special significance when compared with several studies cited in the empirical literature review, which identify a positive role for institutional quality in renewable energy outcomes. Rather than simply contradicting that literature, our result suggests that the relationship is more context-specific and more sensitive to measurement method than is typically assumed. This finding should not be interpreted as evidence that the State is irrelevant; rather, it indicates that a broad measure of administrative and regulatory capacity fails to accurately capture the specific components that render renewable energy projects viable and financeable. In theoretical terms, this finding does not undermine institutional economics; rather, it refines its empirical application by suggesting that, in Latin America, a broad indicator of government effectiveness may be too aggregated to reflect the sector-specific institutional characteristics that make these projects viable and financeable. This is also consistent with the political economy of the energy transition, which emphasizes that general administrative capacity is not always sufficient to redirect capital away from entrenched conventional sectors unless accompanied by more specific forms of regulatory credibility, investment coordination, and implementation capacity. In the Latin American context, it therefore seems more plausible to posit that the energy transition responds less to "government efficiency" in a broad sense and more to concrete capabilities, such as contractual predictability, investment frameworks, institutional coordination, and technological and financial absorptive capacity. In this regard, the ND-GAIN readiness indicator appears to capture these enabling conditions more effectively than a more aggregated measure of government effectiveness. The divergence from previous findings may therefore be attributable to both regional particularities and differences in measurement: whereas other studies typically employ broader international samples or alternative governance indicators, this study focuses specifically on Latin America and compares a general governance measure with an institutional indicator that is more investment-oriented. From this perspective, the results do not imply that institutions do not matter; rather, they refine existing knowledge by demonstrating that not all institutional dimensions shape the nexus between finance and renewable energy in the same way. Thus, hypothesis 2 is partially accepted.

This broader interpretation is reinforced when the sample is divided into the periods before and after the Paris Agreement. During 2002–2014, both readiness and financial development exhibit negative direct effects; however, their interaction is positive and highly significant. This indicates that, during that stage, the financial channel was activated only when climate readiness exceeded a certain minimum threshold. This dynamic is consistent with an early phase of the transition, characterized by still-uneven regulatory frameworks, a heavy reliance on traditional energy sources, including conventional hydroelectricity, and a lower level of maturity in the green market. Under these conditions, greater financial depth could even be associated with a lower share of renewable energy, likely because capital was being channeled toward conventional projects perceived as safer and more profitable. This interpretation aligns with the empirical literature reviewed earlier, particularly those studies demonstrating that finance contributes positively to renewable energy deployment only when complementary institutional conditions are sufficiently developed.

By contrast, in the post-2015 period, this pattern shifts. The model continues to demonstrate a good fit; however, readiness no longer exhibits direct significance, and the interaction between finance and readiness weakens, even becoming slightly negative. The most plausible explanation is not that institutions have ceased to matter, but rather that the primary obstacle has changed. Since 2015, the region appears to have met a minimum regulatory standard, diminishing the importance of readiness as a primary source of variation. The challenge now lies in building more specialized capabilities to structure, manage, and render renewable energy projects attractive to investors. In summary, financial deepening will not lead to large-scale green investment unless there are sufficient technically sound, well-structured projects ready to receive financing. In this regard, the results from the post-2015 period refine the existing literature by suggesting that, once a minimum regulatory floor has been established, the binding constraint may shift away from broad institutional preparedness and toward more specific capabilities at the project and financial-market levels.

This interpretation is further supported by two additional considerations. On the one hand, green capital may be concentrated in the region's most advanced economies, thereby diluting the average marginal effect within a broader regional analysis. On the other hand, the post-2015 period is shorter, which reduces statistical power in a context where the volume of financed green projects may still be limited. Consequently, rather than interpreting these results as evidence that the financial mechanism has vanished, it seems more appropriate to view them as a signal of a consolidation phase for the green market in Latin America.

Robustness checks reinforce this interpretation. Extending the Driscoll–Kraay correction (lag = 3) does not alter the underlying pattern, nor does the exclusion of Paraguay, an outlier due to its heavily hydroelectric energy matrix, eliminate the central mechanism. In both exercises, financial development continues to show an adverse or insignificant effect when enabling conditions are insufficient, while the interaction term retains the expected sign above the threshold. This suggests that the finding does not depend on a particular specification or a single country, but rather reflects a broader regional regularity. In this sense, hypothesis 3 is widely supported.

Concisely, the study's empirical message is sequential: first, enabling conditions must be in place, and only then can finance play its role. However, the results also indicate that, particularly since 2015, broad institutional improvements alone no longer appear sufficient. For financial deepening to become a statistically robust driver of the energy transition, it must be accompanied by specifically "green" instruments, reduced regulatory risk, and a sufficient pipeline of bankable projects. From a public policy perspective, this points to at least three fronts: reducing regulatory and implementation risks through clear rules and enforceable contracts; expanding green financial instruments, ideally denominated in local currency and backed by guarantees, internationally accepted taxonomies, and development banks; and strengthening the technical and institutional readiness of projects through technological and human capital, so that available liquidity can be effectively transformed into renewable energy investment. Without this combination, capital inertia will continue to favor traditional sectors and delay the achievement of the region's climate objectives.

In this regard, a broader policy lesson may also be drawn from China's experience, not as a model to be transplanted directly, but as a useful benchmark for understanding how finance and institutions can be aligned through concrete policy mechanisms. China's transition strategy has combined long-term state-led planning, formal carbon peaking and carbon neutrality targets, green finance guidance for banks and insurers [105], and a national carbon market within a broader framework aimed at building a clean and efficient energy system. Recent evidence further suggests that policy-driven green and carbon finance initiatives in China can shape transition incentives and influence structural change in the energy system when they are embedded within a coordinated institutional architecture [106,107]. This experience reinforces the central implication of our findings: Financial mobilization becomes more effective when embedded in a coherent institutional framework rather than relying solely on financial depth. For Latin America, the most relevant lesson is therefore not one of scale, but of policy design. Certain elements of the chinese approach appear contextually adaptable, particularly the role of public or development banks in de-risking early-stage investment, the provision of clearer medium-term planning signals for renewable deployment, and a stronger alignment between financial regulation and decarbonization objectives. At the same time, the chinese case also points to pitfalls to avoid, including uneven regional implementation and governance bottlenecks, as recent assessments of China's green finance system show that progress across instruments and jurisdictions has been mixed rather than uniform [108,109]. In this sense, the international comparison reinforces rather than alters our main conclusion: what ultimately matters is not the importation of a foreign model, but the development of country-appropriate institutional mechanisms that first strengthen climate readiness and then enable finance to scale up renewable investment more effectively.

5. Conclusions

This study examined whether financial development and institutional conditions can accelerate the adoption of renewable energy in Latin America. Drawing on a balanced macroeconomic panel of 16 countries spanning the 2002–2021 period, and employing a two-way fixed-effects model with Driscoll–Kraay standard errors, the results convey a clear and policy-relevant message: Finance is not "green" in and of itself. At levels close to the regional average for climate readiness, greater financial deepening is associated with a lower share of renewable energy. However, this relationship is not linear and is context-dependent. When readiness exceeds an identifiable threshold, approximately +1.1 SD above the mean, the marginal effect of financial development becomes positive and statistically robust. Furthermore, this threshold mechanism remains stable under reasonable lag specifications and even after excluding outliers, suggesting that climate readiness should not be viewed as a secondary factor, but rather as the enabling condition that determines whether financial deepening genuinely translates into effective decarbonization.

This finding supports public policy recommendations that are sequential in nature and grounded in measurable criteria. In practice, closing the estimated annual financing gap required to meet the objectives of the Paris Agreement, calculated at $150 billion [83], involves not merely mobilizing additional resources, but rather rendering the transition truly investment-ready. This entails elevating countries above the readiness threshold and, once that benchmark is reached, expanding the instruments available to effectively channel capital toward renewable energy projects. Under this logic, a country situated at +1.0 SD of climate readiness might be considered nearly ready, yet still falls short of the point at which finance systematically and sustainably supports the deployment of renewables.

Only when a country advances, for instance, toward +1.2 SD, meaning above the estimated threshold, does financial deepening have a statistically higher probability of translating into concrete results within the renewable energy sector.

Accordingly, the policy implications can be understood in two linked phases. Phase 1 applies to countries below or near the readiness threshold. In this stage, the priority is to raise this variable by strengthening absorptive capacity and reducing the risks that prevent finance from flowing into renewable energy projects. This includes reducing regulatory and contractual risk through standardized, bankable power purchase agreements (PPAs), clear rules for public procurement and market operations, and enforceable contractual terms. It is also crucial to mitigate execution risk through one-stop permitting shops, transparent licensing criteria with defined timelines, and clear standards for connection to and integration with the electricity grid. Added to this is the need to curb discretion and corruption in licensing and public procurement processes, for example, through digitalization and the systematic disclosure of information regarding auctions and contracts. Likewise, it is fundamental to ensure long-term consistency in public policies, including tariff and market design, regulatory oversight, and energy planning, in order to reduce risk premiums. In this phase, public resources, particularly multilateral financing channeled through development banks, can play a highly catalytic role by helping resolve constraints that typically deter private-sector entry.

Phase 2 applies once sufficient climate readiness and absorptive capacity have been established. At that point, the policy focus should shift toward mobilizing and scaling specialized green finance so that available liquidity is effectively transformed into renewable energy investment. This includes facilitating infrastructure financing with longer tenors, providing financing in local currency whenever possible, and utilizing credit-enhancement mechanisms to lower the cost of capital. It also requires expanding the use of green bonds and other available instruments, while strengthening technical capacities for project development, grid integration, and operations and maintenance through training and partnerships with international institutions in the energy and financial sectors, such as development banks. Complementing this is enhanced data transparency on the energy system, including grid congestion, curtailment, dispatch, and resource mapping, to reduce information asymmetries that drive up financing costs. The identified mechanism, therefore, implies that public resources, particularly multilateral financing channeled through development banks, must be deployed strategically in two stages: first, to raise climate readiness above the estimated threshold, and then to mobilize private capital once sufficient absorptive capacity has been established.

This sequencing also helps explain why the institutional improvements observed after 2015 within the analyzed panel did not automatically translate into robust progress in renewable energy. Enhancing climate readiness is a necessary condition, but it is not sufficient on its own. Absent critical mass of green financial instruments or a broad pipeline of bankable projects, aggregate financial deepening may, in practice, remain neutral in its impact. In other words, general improvements in the institutional environment are insufficient on their own unless accompanied by concrete mechanisms that convert available capital into effective green investment.

Given that the analysis relies on comparable macro-indicators, the study does not allow for a complete disaggregation of sectoral channels, such as the distinction between electricity generation and thermal applications, or between modern renewables and traditional hydroelectricity. Nor does it permit a detailed examination of project-level mechanisms, such as contractual structures, technology-specific capital costs, or the quality of the project pipeline. Consequently, future research should incorporate sectoral and technology-specific metrics, as well as more granular data on green financing instruments, the regional composition of credit flows, and energy project-level databases. This would allow for a more precise assessment of how regulatory reforms and specific instruments reduce financing costs and accelerate the deployment of renewable energy, ideally by leveraging regulatory shocks or quasi-experimental designs that strengthen causal identification.

In short, the evidence supports a clear conclusion: financial development, on its own, does not drive the transition toward renewable energy in Latin America. Its contribution becomes positive only when climate readiness exceeds a measurable threshold, and the institutional environment can absorb, direct, and implement investment effectively. This offers a practical rationale for closing the financing gap: first, strengthen readiness by improving regulatory, social, and economic frameworks to unlock public and private investment; then expand green financial instruments and bankable project portfolios to accelerate decarbonization.

Use of AI tools declaration

The authors declare they have not used Artificial Intelligence (AI) tools in the creation of this article.

Conflict of interest

The authors declare no conflicts of interest.

Author contributions

Conceptualization: Herrera, Ni; Methodology: Herrera, Ni; Formal analysis: Herrera; Data curation, Herrera; Writing (original draft): Herrera; Writing (review and editing): Herrera, Ni.

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Appendix

Appendix A1. Latin America: mean renewable electricity 2002–2021.

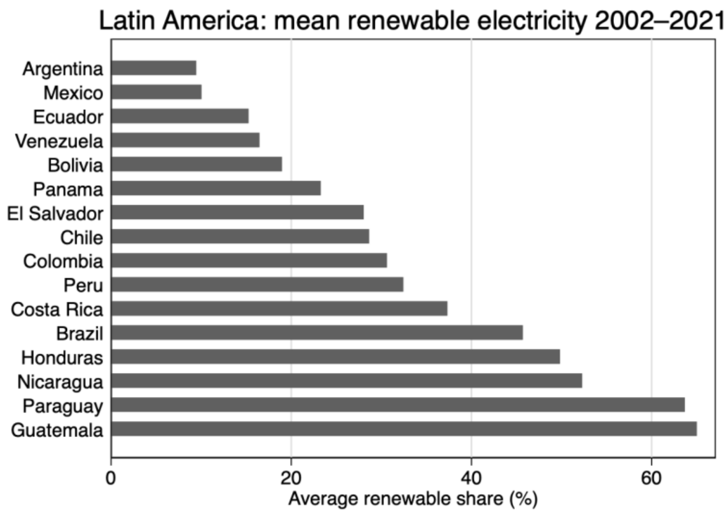

Figure A1. Latin America: mean renewable electricity 2002–2021.

The Figure A1 presents, in an organized, comparative manner, the average share of renewable sources in electricity generation for each of the 16 countries analyzed during the period 2002–2021. The reading is immediate: Guatemala, Paraguay, and Nicaragua top the list, with values close to or exceeding 60%. In all three cases, the high share is explained by the heavy historical dependence on hydroelectricity and, in the final two-year period, by the rapid incorporation of bioenergy (Guatemala) or wind energy (Nicaragua). The intermediate block (Costa Rica–Peru–Chile) maintains its market position between 30% and 40%. The country of Costa Rica relies on a combination of volcanic power and hydroelectric energy, while Peru and Chile have expanded their energy matrix by adding solar and wind power since 2016. The three countries of Argentina, Mexico, and Ecuador have the lowest energy consumption rates, at less than 15%, because their energy systems primarily use natural gas and liquid fuels.

Appendix A2. Marginal effect of financial depth by climate readiness, 2002–2014.

The period 2002–2014 was selected because it precedes the Paris Agreement and avoids the distortion caused by the pandemic; thus, the structural behavior is observed without the massive inflow of external green bonds recorded after 2015. Figure A2 illustrates the hypothesized complementarity mechanism between financial development and climate readiness. Each point on the x-axis corresponds to the standardized value of readiness; the y-axis shows the derivative.

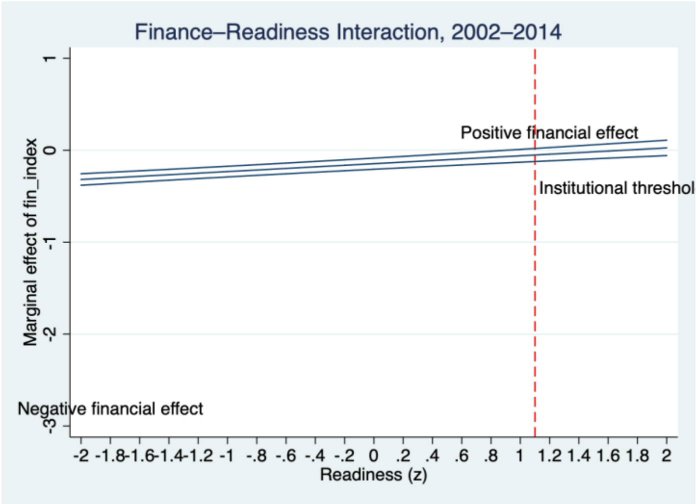

Figure A2. Marginal effect of financial development (fin_index) on renewable energy share by readiness, 2002–2014. Thick line: point estimate; shaded band: 95% CI. Red dashed line: institutional threshold (+1.1 SD) where the effect ceases to be negative, and beyond that level, financial development drives renewable energy adoption.

This graph shows that when regulatory quality is below +1.1 SD above the regional mean, the slope remains slightly negative, indicating that, on average, greater financial market sophistication is associated with a reduction in renewable energy market share. The organization uses its resources to support its existing low-risk business model rather than pursuing environmentally friendly projects. The vertical cutoff at +1.1 SD marks the point where the confidence interval crosses the zero axis: Beyond this level of readiness, the effect of fin_index ceases to be statistically significant and begins to show a positive effect. The marginal effect becomes positive and significant at the threshold point, while showing a limited impact of less than 0.1 percentage points per fin_index deviation. This suggests that, in environments with robust, predictable regulatory frameworks, financial deepening begins to facilitate the financing of renewable technologies, thereby reducing cost and risk barriers. Financial depth functions as a decarbonization accelerator rather than a barrier when institutions meet their required minimum quality standards, according to the research. The development of green financial instruments requires policymakers to establish new regulatory systems that define legal boundaries and enhance agency coordination, or new capital will choose traditional, fast-moving investments instead of supporting climate objectives.

Table A1 shows the marginal effect increases by ~0.18 SD for every 1 additional SD of Readiness. Empirical thresholds appear when the confidence line crosses zero around +1.1 SD; above +1.2 SD, the impact of financial development is already positive and statistically significant. In countries with readiness ≥ +1.6 SD, a 1 SD increase in fin_index is associated with a ≈0.15 SD increase in the renewable energy share (≈2.7 p.p. for the regional average). On the other side, between +0.3 SD and +1.0 SD, the bands encompass zero; there, the financial system is "neutral" with respect to renewables. The study reveals that Readiness scores below −1 SD produce both stable and statistically significant negative effects ($p < 0.001$). The study demonstrates that green finance requires readiness across the social, economic, and regulatory domains to achieve a threshold for success.

Table A1. Marginal effect.

Readiness (z)	Efect dy/dx	IC 95 %	z.	p-value	Interpretation
–2,0	**–0,319**	(–0,381; –0,256)	–9,94	<0,001	Strongly negative and significant effect.
–1,0	–0,247	(–0,308; –0,186)	–8,37	<0,001	Still negative; magnitude ≈ –0.25 SD.
–0,6	–0,180	(–0,239; –0,121)	–6,63	<0,001	
–0,2	–0,113	(–0,173; –0,054)	–5,02	<0,001	
+0,0	–0,066	(–0,124; –0,008)	–2,04	**0,041**	First value still negative but marginally significant
+0,4	−0,019	(−0,078; +0,041)	−0,74	0,459	No longer significant (band includes 0).
+0,8	−0,011	(−0,156; +0,134)	−0,15	0,883	Virtually no effect.
+1,2	+0,077	(+0,009; +0,145)	+2,24	**0,025**	Becomes positive and significant
+1,6	+0,154	(+0,045; +0,262)	+2,74	0,006	The favorable effect is reinforced.
+2,0	+0,253	(+0,093; +0,414)	+3,09	0,002	Maximum observed in the range.

Appendix A3. Hydropower share by country (2002–2021)

Table A2. Hydropower share by country (2002–2021).

Country_name	Hydro_mean	Hydro_sd	Hydro_min	Hydro_max	z_h	Extreme
Argentina	32.30	8.60	16.47	53.03	−0.69	no
Bolivia	34.45	8.72	18.48	52.64	−0.60	no
Brazil	73.15	10.10	55.30	84.02	0.94	no
Chile	35.61	9.39	21.98	52.66	−0.55	no
Colombia	73.18	6.55	61.79	82.94	0.94	no
Costa Rica	74.38	4.43	65.74	81.12	0.99	no
Ecuador	58.86	11.10	44.26	79.39	0.37	no
El Salvador	29.91	3.80	22.08	34.83	−0.78	no
Guatemala	38.55	5.73	30.02	46.24	−0.44	no
Honduras	33.05	5.50	22.81	43.80	−0.66	no
Mexico	10.46	1.85	6.88	14.55	−1.56	no
Nicaragua	10.80	2.80	4.94	15.89	−1.54	no
Panama	59.98	6.58	43.75	70.12	0.42	no
Paraguay	99.97	0.12	99.43	100.00	**2.01**	**yes**
Peru	66.04	10.36	46.79	82.06	0.42	no
Venezuela	67.65	6.61	58.28	79.13	0.72	no

Using the annual hydropower share in the electricity generation series (hydro_pct), the mean, standard deviation, minimum, and maximum (2002–2021) were calculated by country. To identify extreme cases, the national mean was standardized with respect to the regional average (≈ 49.5%) and its standard deviation (≈ 25.3%), and the z score was reported. The upper tail at 5% is used to identify extremely hydro-dependent countries based on their z-scores, which exceeded 1.96. The area shows a broad range of values because national averages span from 10–13% (Panama, Mexico) to 100% (Paraguay). The only extreme case is Paraguay, which has a z-score of 2.00 and shows 100% mean values with no variation; the result confirms its need for exclusion in robustness tests, as hydro data approaches 100%, which could distort regional findings. A high but not extreme group ($z < 1.96$) includes Costa Rica (74%), Colombia (73%), Brazil (73%), Venezuela (68%), and Peru (66%): hydro-intensive countries, but without crossing the statistical threshold for "extreme." The energy bases of Argentina, Bolivia, Chile, and Honduras fall in the low-middle range at 60–10%, while El Salvador, Guatemala, Panama, and Mexico show energy base values of 30%, 38%, 58%, and 10%, respectively. The energy base shows structural heterogeneity, as indicated by the results in Table A2. The evidence supports treating Paraguay as a hydro-dependent outlier in robustness checks (without altering the main sample of 16 countries) and referring to the rest of the study as "high hydro or extreme"

Appendix A4. Illustrative comparison of country's readiness positions relative to the estimated +1.1 SD threshold (2002–2021).

Table A3. Country's position relative to the identified threshold.

Country	Mean readiness score	Mean readiness z-score	Position relative to threshold	Years above +1.1 SD	Mean renewable share (%)	Renewable policy / institutional featu	Main remaining bottleneck	Interpretation for Finance → Renewables
Chile	0.516	2.553	Above threshold	20	28.645	More stable policy environment; stronger planning and investment conditions	Grid expansion and execution constraints	Finance is more likely to support renewables because readiness conditions are consistently strong.
Costa Rica	0.396	1.072	Near threshold	9	37.320	Relatively strong institutional coordination and policy continuity	Limited market depth and scaling constraints	Finance can become supportive, but the effect may remain sensitive because readiness is near rather than clearly above the threshold.
Mexico	0.376	0.817	Below threshold but recurrently near	8	10.030	Intermediate readiness and some investment capacity	Inconsistent translation of readiness into renewable deployment	Finance may remain mixed or unstable in its effect.
Brazil	0.353	0.535	Below threshold but recurrently near	4	45.695	Large financial system with some readiness strengths	Capital may still flow to conventional sectors absent stronger enabling conditions	Financial depth alone is insufficient without stronger enabling conditions.
Peru	0.334	0.297	Below threshold	0	32.430	Intermediate readiness with improving absorptive conditions	Project pipeline and institutional coordination challenges	Finance may support renewables only selectively unless enabling conditions strengthen further.
Argentina	0.326	0.204	Below threshold	0	9.440	Moderate readiness but unstable policy continuity	Macroeconomic and regulatory uncertainty	Financial deepening is unlikely to translate consistently into renewable deployment under unstable conditions.
Colombia	0.323	0.156	Below threshold	0	30.610	Moderate readiness and relevant institutional capacity	Implementation and coordination constraints	Finance may support renewables, but not yet in a uniform or robust way.
Panama	0.319	0.109	Below threshold	0	23.275	Moderate readiness and some institutional capacity	Scale and project bankability limitations	The finance-renewables channel may remain partial or uneven.
El Salvador	0.297	-0.155	Below threshold	0	28.040	Lower-mid readiness with some policy capacity	Investment absorption and execution constraints	Finance is unlikely to operate as a strong lever without broader readiness improvements.
Ecuador	0.278	-0.395	Below threshold	0	15.255	Below-threshold readiness conditions	Institutional and execution risks	Financial deepening is less likely to translate into renewable expansion.
Paraguay	0.260	-0.613	Below threshold	0	63.680	Below-threshold readiness in a hydro-dominated system	Extreme hydro dependence limits comparability	The finance-renewables channel is difficult to observe given the structure of the energy mix.
Bolivia	0.254	-0.687	Below threshold	0	18.960	Below-threshold readiness conditions	Weaker absorptive and regulatory capacity	Finance is unlikely to systematically support renewable diversification.
Guatemala	0.254	-0.692	Below threshold	0	65.005	Below-threshold readiness conditions	Project execution and coordination constraints	Financial depth is unlikely to shift the energy mix without stronger enabling conditions.
Nicaragua	0.250	-0.744	Below threshold	0	52.280	Below-threshold readiness conditions	Institutional fragility and implementation risk	The finance-renewables channel remains weak or unstable.
Honduras	0.225	-1.055	Below threshold	0	49.825	Well below-threshold readiness conditions	Higher execution and coordination risk	Finance is unlikely to systematically support renewable expansion.
Venezuela	0.197	-1.404	Below threshold	0	16.465	Well below-threshold readiness conditions	High institutional and investment risk	Financial development is unlikely to translate into renewable deployment.

Note: Country means are computed over the balanced 2002–2021 panel. The readiness z-score is calculated using the pooled sample mean and standard deviation of readiness across the full panel to remain consistent with the standardized specification used in the main regressions. "Years above threshold" counts the number of country-years in which standardized readiness exceeds the estimated crossover value of +1.1 SD. The table is descriptive and illustrative; it does not constitute an additional causal test.

Table A3 provides substantive content regarding the threshold identified in the main model. The objective of this table is not to re-estimate the relationship, but rather to demonstrate how the estimated crossover point corresponds to different country profiles within the sample. A first pattern observed is that countries with higher average levels of readiness are also those that spend more years at or above the threshold, suggesting a more stable enabling environment for renewable energy investment. Chile serves as the clearest example, as it remains, on average, clearly above the threshold; this is consistent with the interpretation that financial development is more likely to support renewable deployment when planning capacity, policy continuity, and implementation conditions are comparatively more robust. Costa Rica, for its part, is situated near the threshold, a position that is also informative: rather than representing a fully consolidated case above that point, it illustrates a context in which enabling conditions are relatively advanced, yet may still be affected by structural or market constraints.

A second pattern is that countries situated clearly below the threshold tend to reflect weaker institutional and absorptive conditions. In these cases, the descriptive evidence aligns with the main result of the regression: financial deepening, on its own, is less likely to translate into an expansion of renewable energy, because the surrounding environment is not yet sufficiently credible, coordinated, or prepared for investment. This does not imply that such countries are unable to expand renewable energy; rather, it suggests that the channel linking finance and renewables, as identified in the model, is less likely to operate systematically under those conditions. Intermediate cases, such as countries that, on average, remain below the threshold but surpass it in certain years, prove particularly useful, as they demonstrate that the threshold should not be interpreted as a rigid institutional divide. Instead, it reflects a gradual transition in the quality of the enabling environment. Taken together, the table supports interpreting the value of +1.1 SD as an econometric inflection point with substantive institutional significance, rather than as a mere statistical artifact. The comparison suggests that this threshold is broadly associated with observable differences across countries in policy continuity, implementation capacity, and investment conditions. Consequently, the appendix reinforces the public policy interpretation of the main finding: before financial development can become a robust driver of the energy transition, countries must first attain a minimum level of readiness that renders renewable energy projects more bankable, more predictable, and easier to execute.