

## Do diverse boards accelerate the corporate energy transition? Insights from emerging markets

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### ABSTRACT

Mounting investor expectations and patchy regulatory progress have intensified interest in governance mechanisms that can accelerate the corporate energy transition in emerging markets. This study investigates whether board diversity influences the share of renewable energy within firms' total energy consumption in Latin American listed firms. Using a panel of 65 non-financial companies in the S&P MILA Pacific Alliance Index (Chile, Colombia, Mexico and Peru) for 2020–2024 (N = 325), we estimate linear mixed-effects regressions with firm-level random intercepts. Board heterogeneity is captured through two composite measures: the Structural Diversity Index (ISD) and the Demographic Diversity Index (IDD). Both indices are positively associated with firms' renewable energy intensity; with boards exhibiting higher proportions of women, older directors and foreign directors showing the strongest effects. Among the controls, mandatory clean-energy quotas, larger asset bases, and higher leverage further encourage renewable energy use. Cross-country differences reveal that, despite ambitious policy targets, firms operating in less stable regulatory environments, particularly in Mexico, exhibit lower adjusted renewable energy intensity, underscoring the role of institutional credibility in translating internal governance into environmental outcomes. By offering multi-country evidence from the Pacific Alliance, introducing replicable diversity indices, and focusing on a metric directly aligned with SDG 7, the study advances governance and sustainability research. Practically, the findings suggest that boards diversified along structural and demographic lines, when supported by coherent and predictable regulatory frameworks, can hasten corporate decarbonisation.

### 1. Introduction

Global warming is one of the biggest challenges for society today. In fact, global carbon dioxide emissions have surged to record levels, with fossil fuel CO<sub>2</sub> output reaching about 37.4 billion tonnes in 2024, up 0.8% from 2023, with no clear peak in sight (Global Carbon Project, 2024). The continuous rise in carbon dioxide (CO<sub>2</sub>) emissions, mostly from the burning of fossil fuels, has confronted the international community with an unprecedented challenge (Li et al., 2024; Atif et al., 2021).

The problem is particularly serious in energy-intensive industrial sectors. These high-consumption industries account for a

disproportionate share of emissions; for example, the energy sector (including electricity generation, manufacturing, and transportation) produces roughly 75% of global greenhouse gas emissions (World Resources Institute, 2021). Within this total, electricity and heat production alone account for around 40% of global CO<sub>2</sub> emissions, while heavy industries such as steel and cement contribute a substantial share due to their dependence on fossil fuels and energy-intensive production processes (International Energy Agency, 2023; Markard, J., and Rosembloom, D., 2022). The transport sector adds approximately one-fifth of global energy-related emissions, largely from oil-based fuels (Intergovernmental Panel on Climate Change, 2023).

These sectors are not only carbon-intensive but also structurally

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dependent on long-lived assets, which makes decarbonisation particularly complex. Their operations directly affect ecosystems and public health (Zhao et al., 2022; Adams et al., 2020). Replacing fossil fuels with renewable sources has therefore become an essential requirement for mitigating the impacts of climate change.

In this context, businesses play a central role as they consume large amounts of energy and are responsible for a significant proportion of greenhouse gas emissions (Iceland et al., 2024; Liu et al., 2021; U.S. Environmental Protection Agency, 2020). Indeed, a relatively small number of companies account for an outsized share of emissions—for example, just 100 fossil fuel producers have been linked to 71% of global industrial greenhouse gas emissions since 1988 (Taylor, 2017). However, the corporate energy transition faces three structural obstacles. First, the private investment needed to develop clean energy depends on clear policies (stable and well-defined energy and climate frameworks) and the perception of energy security, which is commonly understood as the availability of reliable, affordable, and sustainable energy supplies (International Energy Agency, 2022; Ang et al., 2015) and, from a corporate perspective, as investor confidence in the stability and predictability of energy systems, which is especially critical in developing economies where policy uncertainty and infrastructure constraints may deter long term private investment (Fadly, 2019). Second, there are marked regional imbalances: while Europe dominates technology and renewable energy share, China has become the leading investor in recent years, and other regions are advancing at uneven speeds. Third, technological and logistical barriers persist, making it difficult to align green energy production and consumption (Le et al., 2024). These global challenges underscore the need for effective corporate governance responses. Accordingly, increasing attention is being directed toward the role of boards of directors (hereafter, “boards”) as catalysts for the corporate energy transition.

Meanwhile, the growing prominence of Environmental, Social, and Governance (ESG) criteria has created additional incentives for companies to adopt sustainable practices. ESG represents an investor-oriented framework that translates sustainability issues into measurable indicators used in financial decision-making and risk assessment (Gillan et al., 2021; Friede et al., 2015; Eccles et al., 2014).

While earlier literature has traditionally framed firms’ social and environmental responsibilities under the concept of Corporate Social Responsibility (CSR), more recent approaches have shifted towards ESG frameworks, which provide a more structured and investor-oriented perspective by translating sustainability dimensions into measurable indicators relevant for financial decision-making. In this sense, ESG metrics provide information about firms’ exposure to environmental and social risks, as well as the quality of their governance structures (Gillan et al., 2021). ESG represents an investor, recent research also highlights important challenges related to the measurement and comparability of ESG ratings across providers (Berg et al., 2022).

As a result, better ESG performance is often associated with lower risk, improved access to capital, and higher market value (Flammer et al., 2019). This market-driven valuation channel is particularly relevant in the context of the energy transition, where investors increasingly assess firms’ sustainability strategies and their alignment with long term decarbonisation goals.

This market-driven valuation channel works more effectively when regulatory bodies are robust and enforcement is predictable. In such contexts, investors tend to reward firms who’s disclosed ESG metrics reflect genuine risk mitigation and regulatory compliance. However, in many Latin American countries, institutional frameworks remain fragile, with weak regulatory systems, limited enforcement capacity, and frequent regulatory instability, which undermines the effectiveness of formal regulation (De Lange, 2024). In these settings, internal corporate governance mechanisms—such as a diversified and independent board of directors—can play a decisive role by compensating for weak external pressures, strengthening oversight, and aligning managerial incentives with long-term environmental objectives (García-Sánchez et al., 2021).

Understanding how board characteristics respond to rising environmental demands is therefore crucial (Beji et al., 2021). Prior research links board gender diversity, size, independence, and internationalization to corporate environmental behavior, ranging from clean-energy adoption to emissions reduction targets (Ashraf et al., 2025; Edigbo-nya and Odusanya, 2025; Borghesi et al., 2014), with gender balance emerging as a particularly salient dimension driven by stakeholder and policy pressure (Amorelli and García-Sánchez, 2021). Managers ultimately translate these demands into concrete actions, such as renewable power purchase agreements (PPAs), long-term contracts to procure renewable electricity, and more diverse boards appear to enhance such responsiveness (Fan and Wang, 2024; Zhang and Kong, 2022). Nevertheless, empirical findings remain mixed, and evidence from Latin America is still limited, particularly regarding how internal governance mechanisms interact with challenging institutional environments.

Against this backdrop, this study examines how the structural and demographic characteristics of corporate boards relate to renewable energy consumption among firms included in the S&P MILA (*Mercado Integrado Latinoamericano*) Pacific Alliance Index over the period 2020–2024. This regional focus is relevant for two main reasons. First, the Pacific Alliance encompasses heterogeneous regulatory frameworks and relatively weak external enforcement, allowing us to observe the compensatory role of internal governance mechanisms (Gómez and García, 2020; Husted and de Sousa-Filho, 2019). Second, the findings contribute to the design of corporate and public policies tailored to the institutional specificities of emerging Latin American markets.

Based on a panel of 325 annual observations of companies between 2020 and 2024 in emerging markets, we observe that (a) both structural diversity indices of the board of directors (e.g., board size, independence, and internationalization) and demographic diversity increase the share of renewable energy in the company’s energy mix, and (ii) a higher proportion of women and the presence of foreign members on the board of directors further amplify this effect, even under conditions of poor or uneven regulatory enforcement. These results offer novel evidence not only for Latin America, but also for various emerging economies characterized by institutional fragility, limited policy enforcement, and frequent regulatory changes. This underscores the strategic importance of robust internal governance mechanisms as a complement or substitute for formal regulatory pressure in driving transitions toward corporate sustainability.

This study makes three main contributions to the literature. First, it provides novel multi-country evidence from Pacific Alliance emerging markets on how board diversity—both structural and demographic—shapes firms’ renewable energy use. Second, it advances existing research by moving beyond isolated board attributes and introducing replicable composite diversity indices that capture the synergistic effects of board structures and demographics. Third, by focusing on renewable energy intensity and incorporating recent data, the study offers timely insights into how internal governance mechanisms can accelerate the corporate energy transition under heterogeneous and imperfect regulatory frameworks.

The rest of the article is organised as follows: Section 2 develops the theoretical framework and hypotheses; Section 3 details the methodology; Section 4 presents the results; Section 5 discusses the implications and limitations; and Section 6 presents the main conclusions.

## 2. Literature review and study hypotheses

### 2.1. Theoretical background

This study is based on two complementary pillars: internal governance (agency theory and resource dependence) explaining how board structures align incentives and mobilise resources for long-term investment (Fama and Jensen, 1983; Pfeffer and Salancik, 2015); and external pressures—stakeholder and institutional theories—showing how stakeholder demands and coercive, normative, and cognitive pressures drive

firms' adoption of renewable energy (Freeman, 1984; DiMaggio and Powell, 1983).

## 2.2. Internal forces shaping green decisions

In this study, internal forces refer to firm-level factors that shape strategic decision making. In line with the corporate governance literature, these forces are operationalised as internal governance mechanisms, particularly those related to board structures and oversight processes that influence environmental investments and renewable energy adoption (Fama and Jensen, 1983; Hillman et al., 2000).

From the perspective of the board's internal governance mechanisms, Agency Theory and Resource Dependency Theory converge on aspects of supervision, control, and access to critical resources. Agency Theory examines the principal-agent relationship, proposing governance structures, such as the board of directors, to monitor management and mitigate agency costs (Eisenhardt, 1989; Fama and Jensen, 1983). In this approach, the board is fundamental in designing internal controls that align managers' incentives with shareholders' interests, thereby reducing conflicts when allocating capital to long-term investments, including renewable energy projects. In this context, these governance mechanisms directly influence green decisions, understood as strategic choices related to renewable energy adoption, decarbonisation, and other sustainability-oriented investments.

Furthermore, Resource Dependency Theory proposes that companies operate in an interdependent environment where success depends on obtaining and managing vital resources (Pfeffer and Salancik, 2015). In this context, the board acts as a bridge between the company and its external environment, facilitating access to information, strategic networks, and essential inputs (Hillman et al., 2000). Although this bridging function connects the firm to external actors, it is exercised through internal governance processes, as boards internalize external pressures and translate them into strategic decisions. This resource-acquisition function is especially relevant for green decisions, as the transition toward renewable energy often requires access to external knowledge, technological partnerships, and sustainable financing sources.

Accordingly, the board's boundary-spanning role directly shapes internal green decisions by influencing how firms allocate resources, assess environmental risks, and commit to renewable energy investments. Both theories emphasize the strategic role of the board in internal governance and resource management. A diverse board, bringing together varied experience in sustainable practices, technological innovation, and regulatory compliance, can more effectively shape and implement strategies that optimize the company's resource base to achieve more environmentally friendly outcomes (Hassan and Johari, 2023; Richard, 2000).

Beyond board composition, other internal governance mechanisms, such as sustainability committees, executive incentive structures, and internal environmental policies, may also influence green decisions (Eccles et al., 2014; Flammer et al., 2019; García-Sánchez et al., 2021), although the present study focuses specifically on the role of board diversity.

## 2.3. Stakeholder demands and institutional norms

From external pressures (regulatory, coercive, and market-related), Stakeholder Theory and Institutional Theory offer a framework for understanding how external agents shape a company's sustainability decisions.

Stakeholder Theory (Freeman, 1984) expands the vision of corporate governance by recognizing that companies are responsible not only to their shareholders, but also to their employees, customers, suppliers, local communities, regulatory bodies, and NGOs. These stakeholders put pressure on companies to incorporate social and environmental responsibility practices, not as a mere formality, but as a way to generate

legitimacy and trust. In markets where regulation is weak or enforcement is irregular (as is often the case in several Pacific Alliance countries) the support of socially responsible investors and public visibility are crucial to promoting green energy projects.

Institutional theory holds that coercive (laws and sanctions) and regulatory (ISO standards, ESG certifications) pressures shape organisational behaviour and that, when enforcement is weak, firms often provide limited or unreliable disclosures (Ding and Wang, 2025; Correa-García et al., 2020; Husted and de Sousa-Filho, 2019). Prior research shows that weak institutional environments are associated with lower-quality environmental disclosure and a higher risk of decoupling between stated sustainability commitments and actual practices (García-Sánchez et al., 2021; Marquis and Qian, 2014). To mitigate this risk, robust institutional settings emphasise clear regulatory frameworks, transparency requirements, and measurable environmental targets, which increase accountability and reduce opportunistic behaviour.

Within this context, the board of directors plays a critical mediating role. By incorporating directors with diverse backgrounds, experiences, and stakeholder ties, diverse boards are better equipped to internalise external stakeholder and institutional pressures and translate them into concrete strategic actions, such as investments in renewable energy and long-term decarbonisation initiatives (Zaman et al., 2024; Beji et al., 2021; Hillman et al., 2000). In this way, board diversity helps move firms from symbolic sustainability intentions to effective environmental execution.

## 2.4. Regulatory and economic context of renewable energy in the Pacific alliance

The Pacific Alliance has implemented policies to promote energy transition (Mejía-Montero et al., 2023; Ministry of Energy, 2015), but their application occurs in environments with institutional fragility, intermittent oversight, and frequent changes, which leads to uneven effectiveness across jurisdictions (Mejía-Montero et al., 2023; Correa-García et al., 2020; Husted and de Sousa-Filho, 2019). Examples in Table 1 include Mexico's CEL scheme (35% in 2024; 50% in 2050) with delays and litigation that have mitigated its impact (Secretaría de Energía (SENER), 2022; Mejía-Montero et al., 2023); Chile's progressive quotas towards 20% NCRE in 2025 (Laws 20.257 and 20.698); Colombia's obligation to contract at least 10% renewable energy (Resolution MME 40715, 2019); and Peru's indicative approach with auctions to reach 5% of consumption (Perú, 2008). These strategies reflect political commitment and heterogeneous institutionalities (Mejía-Montero et al., 2023).

Given the limits of public funding, achieving climate goals requires greater involvement from the private sector and strategic direction from corporate boards (Silva et al., 2021). The investment environment has improved but it requires governance structures capable of interpreting risks, responding to regulation, and leading sustainable transformations (González-Ruiz et al., 2023). Despite regulatory advances, academic evidence remains scarce both on the Pacific Alliance as a regional setting and on how regulatory and organisational frameworks jointly shape corporate decisions on clean energy adoption. Few studies examine how internal governance mechanisms, such as board composition and diversity, interact with heterogeneous and uneven regulatory environments to influence firms' renewable energy strategies (Pablo-Romero et al., 2022; Silva et al., 2021).

Taken together, firms' environmental and energy-related decisions are shaped by a combination of internal governance mechanisms, stakeholder pressures, and regulatory and economic conditions. Internal factors such as managerial incentives, sustainability committees, and organisational capabilities, as well as external forces including investor expectations, stakeholder activism, and regulatory frameworks, all influence corporate energy strategies (Freeman, 1984; DiMaggio and Powell, 1983).

Within this broader context, the board of directors occupies a central

**Table 1**  
Policies promoting renewable energy in the countries of the Pacific Alliance.

Country	Regulation type	Start year	Main target	Implementation instruments	Source
Mexico	Mandatory quotas with Clean Energy Certificates (CEL)	Since 2018	35% by 2024; 50% by 2050	CELS and penalties; certificates purchased by large users and suppliers	Secretaría de Energía (SENER) (2022)
Chile	Mandatory Non-Conventional Renewable Energy (NCRE) quotas (Laws 20.257 & 20.698)	Since 2010, it expanded in 2014	5% up to 2014; 15% by 2020; 20% by 2025	Progressive quotas, penalties, regulatory oversight	Ministry of Energy (2015)
Colombia	Mandatory 10% quota for regulated retailers	Law 2019 (in force since 2022)	10% annually from 2022	≥10-year contracts with NCRE generators (FNCR) and official verification	Ministerio de Minas y Energía (2019)
Peru	No mandatory quota; indicative targets and Renewable Energy Auctions (RER)	Since 2008	5% of total consumption	Legislative Decree 1002 and renewable-generation auctions	Perú (2008)

position, as it mediates between internal decision-making processes and external institutional and stakeholder pressures. Internally, the board oversees managerial behaviour, aligns executive incentives, and allocates resources across competing strategic priorities. Externally, it interprets and responds to pressures from investors, regulators, and other stakeholders, translating these expectations into concrete strategic decisions (García-Sánchez et al., 2021; Husted and de Sousa-Filho, 2019).

The effectiveness of this mediating role depends on board characteristics. Structural attributes may strengthen monitoring and control functions, while demographic and experiential diversity can improve the board’s ability to access external knowledge, understand stakeholder expectations, and support complex sustainability-oriented investments. Accordingly, analysing board diversity provides a useful lens to understand how internal governance interacts with external constraints to influence firms’ renewable energy decisions, particularly in emerging markets characterised by institutional fragility.

2.5. Board diversity for clean energy management

This study distinguishes two dimensions of diversity (Ding and Wang, 2025; Zaman et al., 2024; Hafsi and Turgut, 2013): structural diversity, which shapes the framework for oversight and resource allocation; and demographic diversity, which broadens cognitive and social perspectives to advance clean-energy initiatives (see Fig. 1).

In this study, “renewable energy consumption” is understood as the

share of renewable energy in firms’ total energy consumption, rather than an increase in absolute energy use. This operationalization captures firms’ strategic decisions to substitute fossil-based energy sources with renewable alternatives and therefore reflects the adoption and implementation of clean energy strategies discussed in the preceding theoretical sections.

2.6. Structural board diversity

This dimension focuses on how the board of directors is structured to perform its supervisory and decision-making functions. It refers to the formal characteristics that shape its composition and operation, such as the size of the board, the proportion of independent members, the existence of dual leadership (when the CEO is also the chair of the board), the presence of specialized committees, and the degree of equity participation. The literature argues that these characteristics can affect the board’s ability to align the interests of owners and managers (Agency Theory), as well as its ability to facilitate access to key resources in the environment (Resource Dependence Theory).

In this context, various studies have shown that a higher proportion of independent directors strengthens internal control mechanisms and is associated with a higher share of renewable energy in total energy consumption, as it favours long-term decisions (Zhang et al., 2021; Fakoya and Nakeng, 2019). Similarly, larger boards tend to have a wider base of knowledge and perspectives, which can enrich the evaluation of

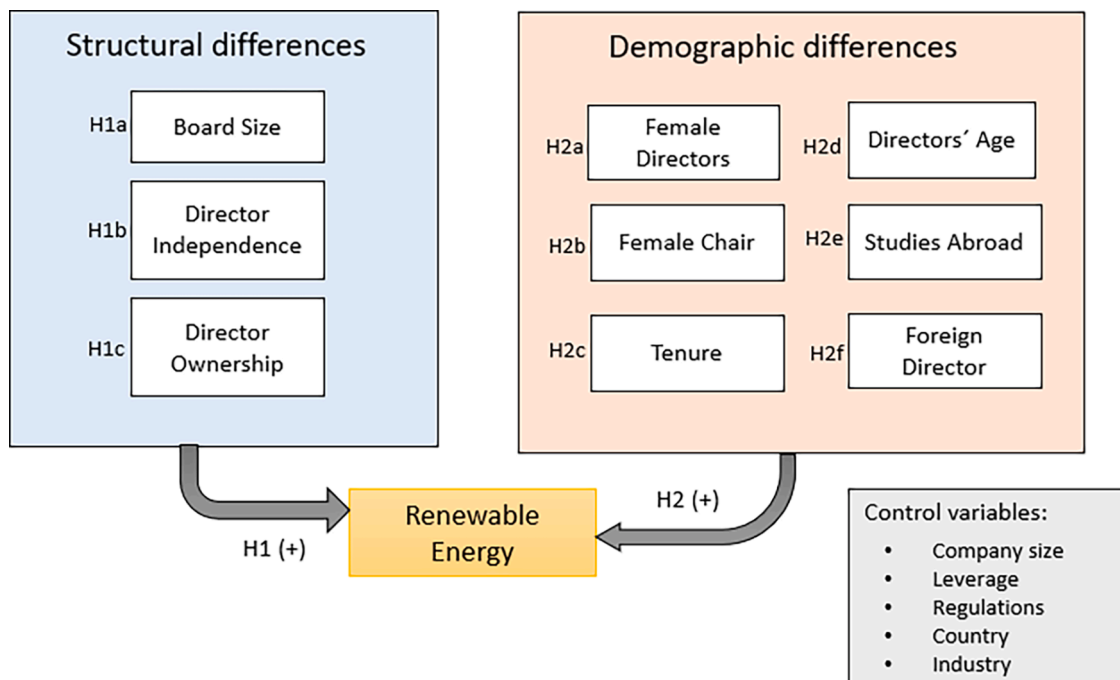


Fig. 1. Conceptual model: boardroom diversity and renewable energy.

clean energy investments, although their effects may vary depending on the context (Zhang et al., 2021).

From the perspective of Resource Dependence Theory, the board not only acts as a control entity, it also acts as a strategic link between the company and its environment. For example, Saha and Khan, 2025 found that, in Bangladeshi companies, these structures increase environmental disclosure related to renewable energy. However, in contexts with weak institutions, such as in Latin America, these structural mechanisms seem to have a limited impact. Abreu et al. (2022) found no significant effects of board independence or size on environmental policies in companies in Brazil, Chile, and Mexico. This result is in line with Institutional Theory, which highlights how formal board rules are only effective when embedded in a robust institutional environment with sufficient regulatory pressure.

Based on the above, the following hypotheses are proposed to examine the relationship between board structural diversity and renewable energy consumption:

**H1.** Structural diversity of the board of directors is positively associated with the share of renewable energy in firms' total energy consumption.

**H1a.** Board size is positively associated with the share of renewable energy in firms' total energy consumption.

**H1b.** The proportion of independent directors is positively associated with the share of renewable energy in firms' total energy consumption.

**H1c.** The presence of owner-directors is associated with the share of renewable energy in firms' total energy consumption.

## 2.7. Demographic board diversity

This dimension focuses on the cognitive and social heterogeneity that individuals bring to the decision-making process and on the personal characteristics of its members, based on characteristics such as female representation, female chair, age, tenure, foreign director, or academic background.

The impact of board demographics on energy sustainability remains a subject of debate: some studies suggest that younger boards, perhaps more sensitive to contemporary environmental challenges and emerging clean technology trends, are more likely to adopt innovative energy solutions (Zhang et al., 2021), while others argue that older directors bring valuable experience and prudence, fostering a long-term strategic vision that also supports sustainable investments (Uyar et al., 2024; Romano et al., 2018; Coles et al., 2008). Beyond age, generational and cultural diversity, including members with international training or education, can enrich the board's strategic debate by introducing complementary perspectives and global best practices, which in turn improve the quality and effectiveness of energy-related decisions (Saha and Khan, 2025; Ali et al., 2014; Muller, 2014).

Empirical findings regarding the impact of female participation on boards of directors on the use of renewable energy are mixed. On the one hand, studies such as that by Atif et al. (2021) find that boards with greater female representation have significantly higher levels of renewable energy consumption, an effect that is intensified when women are independent directors and when a critical mass of at least two members is reached. Complementarily, Uyar et al. (2024) show a positive effect of gender diversity on the use of clean energy, particularly in contexts with active government policies on energy efficiency, suggesting an interaction between external institutional pressures and the internal composition of the board. From the perspective of Stakeholder Theory (Freeman, 1984), these results can be explained by women's greater sensitivity to social and environmental interests, which favours more sustainable corporate decisions.

Although gender diversity on boards of directors is often praised as a driver of more ambitious environmental strategies, the empirical evidence is mixed. In emerging countries, Abreu et al. (2022) find no significant link between female representation on boards of directors and environmental decision-making, a result they attribute to weak

institutional frameworks that restrict the influence of gender minorities. Similarly, Fakoya and Nakeng (2019) report no statistically significant effect of women's presence on the energy performance of South African companies. These findings suggest that diversity per se may have a limited transformative impact unless accompanied by real decision-making power and supportive governance structures. However, from a conceptual standpoint, Pearl-Martinez and Stephens (2016) argue that elevating women to leadership roles in energy can accelerate innovation, foster the transition to clean energy, and promote greater equality within the process. Therefore, demographic diversity represents a strategic advance for sustainable energy management only when it is integrated into institutional arrangements that translate heterogeneous perspectives into effective influence.

Based on the theoretical and empirical review presented, the following hypotheses are proposed:

**H2:** Demographic diversity of the board of directors positively influences the share of renewable energy in firms' total energy consumption.

**H2a.** The proportion of women on the board is associated with the share of renewable energy in firms' total energy consumption.

**H2b.** The presence of a female chairperson is associated with the share of renewable energy in firms' total energy consumption.

**H2c.** Average board tenure is associated with the share of renewable energy in firms' total energy consumption.

**H2d.** Average board age is associated with the share of renewable energy in firms' total energy consumption.

**H2e.** The presence of directors with international education is positively associated with the share of renewable energy in firms' total energy consumption.

**H2f.** The presence of foreign directors is associated with the share of renewable energy in firms' total energy consumption.

## 3. Research design and methodology

### 3.1. Sample

The study uses an annual data panel for the period 2020–2024 composed of the issuing companies that make up the S&P MILA Pacific Alliance index, listed on the stock exchanges of Lima, Santiago, Mexico City, and Colombia.

Since there is no standardized database that reports homogeneous environmental indicators for the region, the values for renewable energy consumption and total energy consumption were compiled manually from sustainability reports, integrated reports, and annual reports available on corporate websites, converting all figures to kWh to ensure comparability.

The characteristics of the board of directors were extracted from the same sources. However, the financial control variables (total assets and leverage) and Standard Industrial Classification (SIC) sector classification, which groups firms according to their primary economic activity, were obtained from the Refinitiv Eikon Database (LSEG), a widely used financial data platform that provides standardized and comparable firm-level information across global markets, preserving accounting consistency and sector comparability.

After cleaning the observations with missing data, the final sample comprises 65 companies (260 observations).

### 3.2. Empirical model variable measurement and estimation strategy

In order to determine the impact of board diversity on renewable energy consumption by Pacific Alliance companies, we propose four econometric models.

Models 1 and 2 capture the structural diversity of the board, while models 3 and 4 focus on demographic diversity. For a holistic perspective, we use composite indices, ISD (Index of Structural Diversity) and IDD (Index of Demographic Diversity). Additionally, we introduce each

attribute separately to identify the main drivers of renewable energy performance.

**Models Testing Hypothesis 1:**

**Model 1:**  $\text{Log}(\text{Renewable Energy}) = \beta_0 + \beta_1 \cdot \text{ISD} + \beta_2 \cdot \text{Company\_size} + \beta_3 \cdot \text{Leverage} + \beta_4 \cdot \text{Regulations} + \sum_j \gamma_j \cdot \text{Country} + \sum_j \gamma_j \cdot \text{Industry} + u_i + e_{ij}$

**Model 2:**  $\text{Log}(\text{Renewable Energy}) = \beta_0 + \beta_1 \cdot \text{Board\_Size} + \beta_2 \cdot \text{Independence} + \beta_3 \cdot \text{Ownership} + \beta_4 \cdot \text{Leverage} + \beta_5 \cdot \text{Company\_size} + \beta_6 \cdot \text{Regulations} + \sum_j \gamma_j \cdot \text{Country} + \sum_j \gamma_j \cdot \text{Industry} + u_i + e_{ij}$

**Models Testing Hypothesis 2:**

**Model 3:**  $\text{Log}(\text{Renewable Energy}) = \beta_0 + \beta_1 \cdot \text{IDD} + \beta_2 \cdot \text{Company\_size} + \beta_3 \cdot \text{Leverage} + \beta_4 \cdot \text{Regulations} + \sum_j \gamma_j \cdot \text{Country} + \sum_j \gamma_j \cdot \text{Industry} + u_i + e_{ij}$

**Model 4:**  $\text{Log}(\text{Renewable Energy}) = \beta_0 + \beta_1 \cdot \text{Female}_{\text{directors}} + \beta_2 \cdot \text{Female}_{\text{Chair}} + \beta_3 \cdot \text{Age} + \beta_4 \cdot \text{Tenure} + \beta_5 \cdot \text{Foreign}_{\text{directors}} + \beta_6 \cdot \text{Studies}_{\text{abroad}} + \beta_7 \cdot \text{Leverage} + \beta_8 \cdot \text{Company\_size} + \beta_9 \cdot \text{Regulations} + \sum_j \gamma_j \cdot \text{Country} + \sum_j \gamma_j \cdot \text{Industry} + u_i + e_{ij}$

For our study, we constructed the dependent variable renewable energy, which captures renewable energy consumption, defined as the ratio between renewable energy consumption in kWh and total energy consumption in kWh. This variable is modelled in natural logarithms to mitigate asymmetries and facilitate the interpretation of the coefficients.

$$\text{RenewableEnergy} = \frac{\text{kWhofrenewableenergy}}{\text{kWhoftotalenergyconsumption}}$$

The independent variables were synthesized into two composite indicators: the Structural Diversity Index (ISD) and the Demographic Diversity Index (IDD), constructed from nine explanatory variables and five control variables detailed in Table 2. In practical terms, these indices allow us to summarize multiple board attributes into a single measure, capturing overall board heterogeneity while reducing model complexity and multicollinearity. The use of indices is a well-established practice in corporate governance literature (Ding and Wang, 2025; Zaman et al., 2024; Hafsi and Turgut, 2013; Bebchuk et al., 2009) and, specifically, so-called “pluralism indices” have been applied to quantify the heterogeneity of boards at different levels (Molz, 1995). For the ISD, the average distance between samples metric described by Ding and Wang (2025), Hafsi and Turgut (2013) and formalized by Deza & Deza (2009) was applied: the multivariate distance of each firm from all others was calculated, considering the six structural diversity variables simultaneously, this value was averaged, and finally normalized in the 0–1 interval. The IDD, meanwhile, was calculated by stratification into tertiles following Hafsi and Turgut (2013): continuous variables were

assigned discrete values of 0, 1, and 2 when the company data fell in the lower, middle, or upper tertile of the sample distribution, respectively, while dichotomous variables received 0 or 1 depending on the absence or presence of the attribute.

Our model includes nine independent variables that capture the structure and composition of the board of directors, selected in line with previous evidence (Abreu et al., 2022; Zhang et al., 2021; Fakoya and Nakeng, 2019). To mitigate potential specification bias, we add several financial controls: firm size, measured as the natural log of total assets; leverage, defined as total liabilities divided by total assets, following Correa-García et al. (2020) and El Ghouli et al. (2016); and an industry categorical variable (operationalized as SIC-based dummy indicators). We also include a binary variable, Regulations, coded YES when a company is subject to a rule that mandates a minimum share of renewable energy and NO otherwise. Table 2 summarizes the definition and measurement of all variables.

To test our hypotheses, we estimated linear mixed-effects models, which are well suited to multi-level data because they combine fixed effects with a firm-level random component, thereby capturing unobserved heterogeneity and intra-group dependence (Snijders and Bosker, 2012).

**3.3. Measurement of renewable energy consumption**

Data on total energy consumption and renewable energy use were manually collected from firms’ sustainability reports, integrated reports, and annual reports published on their official corporate websites. For firms operating in Latin American emerging markets, standardized commercial databases (e.g., Bloomberg, Refinitiv Eikon) do not provide consistent or comprehensive information on renewable energy consumption at the firm level, making company disclosures the most reliable and widely used source in prior sustainability research.

To ensure comparability across firms and years, all reported energy figures were harmonized into kilowatt-hours (kWh). When energy consumption was disclosed in alternative units (e.g., MWh, GJ, or TJ), standard conversion factors were applied. In cases where firms reported renewable energy as a percentage of total consumption, absolute renewable energy values were derived using the corresponding total energy figures. Only energy explicitly identified as renewable (such as solar, wind, hydro, biomass, or certified renewable electricity) was included.

**Table 2**  
Independent and control variables.

Index	Description	Notation	Variable	Measure	Data source
ISD	Structural diversity	Board size	Board size	Board directors (n)	Corporate reports (sustainability, integrated, and annual)
		Independence	% independent directors	Independent directors (n) / All directors (n)	Corporate reports (sustainability, integrated, and annual)
		Ownership	% owner-directors	Owner directors (n) / All directors (n)	Corporate reports (sustainability, integrated, and annual)
IDD	Demographic diversity	Female directors	% female directors	Female directors (n) / All directors (n)	Corporate reports (sustainability, integrated, and annual)
		Female chair	Female Chair	This variable takes the value YES if the Board has a female Chair, and NO otherwise.	Corporate reports (sustainability, integrated, and annual)
		Tenure	Tenure	Average tenure of directors (years)	Corporate reports (sustainability, integrated, and annual)
		Age	Age	Average age of directors	Corporate reports (sustainability, integrated, and annual)
		Studies abroad	Studies abroad	Directors with education abroad (n) / All directors (n)	Corporate reports (sustainability, integrated, and annual)
		Foreign director	% Foreign directors	Foreign directors (n) (All directors (n)	Corporate reports (sustainability, integrated, and annual)
		Control variables	Company size	Company size	Total assets (thousands of US dollars)
Leverage	Leverage	Total liabilities / Total assets	Refinitiv Eikon Database		
Regulation	Regulation	This variable takes the value YES if the company is subject to a regulation that mandates a minimum share of renewable energy, and NO otherwise.	National regulatory frameworks / legal sources		
Country	Country	Chile, Mexico, Colombia and Peru	Refinitiv Eikon Database		
Industry	Industry	Standard Industrial Classification (SIC) system	Refinitiv Eikon Database		

Regarding the distinction between on-site generation and externally acquired renewable energy (e.g., via power purchase agreements or renewable energy certificates), both sources were included when firms explicitly classified them as renewable in their disclosures. When such distinctions were not reported, renewable energy figures were treated conservatively and classified based on firms' explicit statements to minimize misclassification risk.

To mitigate potential disclosure bias (where firms with stronger governance structures may provide more detailed sustainability reporting) we conducted additional robustness analyses by estimating adjusted marginal means across countries and industries and by assessing the consistency of results within relatively homogeneous sectors. The persistence of the main results across these specifications suggests that the findings are not driven solely by reporting intensity but reflect substantive differences in renewable energy adoption.

### 3.4. Descriptive statistics

As shown in Table 3, the dependent variable measured as the logarithm of the share of renewable energy in total energy consumption shows substantial dispersion across firms and years (Ln Renewable Energy, mean = -2.03; SD = 1.88), with values ranging from -6.91 to approximately zero. The pronounced right-skewness of the underlying distribution motivates the logarithmic transformation adopted in the regression analyses.

Boards comprise on average 9.98 directors (SD = 3.12), of whom 41.7% are independent and 24.3% are owner-directors. Female representation remains limited: women hold 15.7% of board seats, and only 6.5% of firms have a female chair. Directors are, on average, 61.5 years old (SD = 4.24) and have served on the board for 10.3 years (SD = 5.36).

Regarding international exposure, 19.0% of directors are foreign nationals and 52.7% have completed part of their education abroad. These characteristics are summarized by two composite indices: the Structural Diversity Index (ISD), scaled from 0 to 1 (mean = 0.262; SD = 0.242), and the Demographic Diversity Index (IDD), scaled from 0 to 10 (mean = 4.45; SD = 2.16).

At the firm level, total assets range from approximately USD 0.37 million to USD 92.26 million (mean = USD 10.29 million; SD = USD 14.81 million), while the average leverage ratio is 0.58 (SD = 0.16). Finally, 56.9% of the observations correspond to firms operating in industries subject to mandatory renewable energy regulation.

**Table 3**  
Descriptive statistics.

Variable	Obs.	Mean	Std. Dev.	Min	Max
ISD	325	0262	0242	0000	1000
IDD	325	4446	2158	0000	10,000
Board_size	325	9978	3123	5000	20,000
Independence	325	0417	0232	0000	1000
Ownership	325	0243	0234	0000	0889
Female_directors	325	0157	0113	0000	0429
Age	325	61,486	4239	53,714	70,769
Tenure	325	10,263	5356	1889	27,455
Studies_abroad	325	0527	0237	0000	1000
Foreign_directors	325	0190	0159	0000	0700
Ln(Renewable Energy)	325	- 2033	1878	-6908	0001
Company_size	325	10.286.137	14.807.284	374.494	92.260.585
Leverage	325	0580	0155	0287	1532
<b>Variable</b>	<b>Obs.</b>	<b>Absol. Freq</b>		<b>Relative Freq.</b>	
		<b>YES</b>	<b>NO</b>	<b>YES</b>	<b>NO</b>
Female_Chair	325	21	304	0065	0935
Regulation	325	185	140	0569	0431

## 4. Results and interpretation of key findings

### 4.1. Structural board diversity and its influence on renewable energy

Model 1 (M1) shows that the Structural Diversity Index (ISD) has a positive and statistically significant coefficient ( $p = 0.004$ ). Substantively, a one-standard-deviation increase in the ISD ( $\approx 0.20$ ) is associated with about a 5–6% rise in renewable-energy use, supporting Hypothesis (H1) and confirming that boards balanced in size, independence, and ownership stakes foster long-term green investment. This finding is consistent with resource dependence theory, which argues that structurally diverse boards broaden their networks and monitoring capacity, thereby directing resources toward long-horizon clean-energy projects (Zhang et al., 2021; Hillman et al., 2000).

When the ISD is disaggregated in Model 2 (M2), none of its individual components (board size, independence, or ownership) becomes significant on its own; the impact emerges only when all three gears operate together, reinforcing the synergistic view advanced by Hafsi and Turgut (2013).

Among the controls, mandatory regulation ( $p = 0.001$ ) and higher financial leverage ( $p < 0.05$ ) increase renewable-energy adoption, whereas firm size matters only in M2 ( $p = 0.023$ ).

The country control variable reveals that, relative to Chile, Mexican firms consume significantly less renewable energy ( $p < 0.01$ ). This result is consistent with prior evidence documenting delays and legal uncertainty in the implementation of Clean Energy Certificates (CELs), frequent regulatory reversals, and grid congestion constraints, which have discouraged private renewable investment despite Mexico's relatively ambitious statutory targets (Mejía-Montero et al., 2023; Secretaría de Energía (SENER), 2022; Husted and de Sousa-Filho, 2019). By contrast, Chile's more stable regulatory framework and clearer long-term policy signals have been shown to facilitate private participation in renewable energy markets (Ministry of Energy, 2015; Mejía-Montero et al., 2023).

At the industry level, mining shows a positive coefficient ( $p = 0.062$ ), likely reflecting recent green PPA contracts, while wholesale trade exhibits a negative effect ( $p < 0.01$ ), perhaps due to scale or space limits for on-site generation. These patterns align with sector-specific evidence indicating that mining firms in Latin America face strong pressure from international buyers and financiers to decarbonize supply chains, whereas wholesale trade firms typically operate with limited physical capacity for renewable generation and lower regulatory exposure (Silva et al., 2021; Pablo-Romero et al., 2022). Finance, insurance, real estate and services also display positive, significant effects, suggesting that stronger reputational pressure and easier access to clean electricity via PPAs or origin certificates lead these reputation sensitive, low energy

intensity sectors to over comply with renewable targets.

The conditional R<sup>2</sup> values (0.83–0.83) indicate that the mix of fixed and random effects explains most of the variance, although the marginal R<sup>2</sup> (M1 = 0.35; M2 = 0.34) shows that unobserved firm level differences remain.

Overall, companies with well-configured boards exhibit markedly higher renewable energy uptake, whereas isolated tweaks to individual board traits are insufficient. These findings, reported in Table 4, extend the emerging-market literature by demonstrating that (even under heterogeneous and unevenly enforced regulatory frameworks) cohesive corporate governance can hasten the energy transition.

#### 4.2. Demographic board diversity and its influence on renewable energy

Model 3 (M3) confirms Hypothesis 2 (H2): the Demographic Diversity Index (IDD) shows a positive, significant coefficient ( $p = 0.001$ ), indicating that boards with greater heterogeneity in gender, age, nationality, and education background are associated with significantly higher levels of renewable energy use. This finding aligns with resource dependence theory, which holds that diversity broadens a firm’s pool of resources and strategic networks, thereby easing the adoption of green technologies (Hillman et al., 2000).

Disaggregating the IDD in Model 4 (M4) reveals additional details. The proportion of women on the board remains positive and reaches marginal significance ( $p < 0.05$ ), supporting H2a and prior evidence that female directors are more attuned to environmental issues (Atif et al., 2021). Female chairmanship and average tenure are not significant, indicating that leadership or lengthy service on its own is not enough to drive renewable investment unless combined with other diversity attributes. By contrast, the presence of foreign directors is positive and highly significant ( $p < 0.001$ ), supporting H2f and the view that overseas directors act as boundary spanners who bring international best practices and global networks. Average board age also exhibits a statistically significant effect, suggesting that age-related experience may play a role in shaping renewable energy decisions. In contrast, the share of directors educated abroad does not reach conventional significance levels (H2e).

Among the control variables, mandatory regulation continues to have a positive impact ( $p < 0.01$ ), in line with institutional theory (DiMaggio and Powell, 1983). Leverage and firm size are also positively associated with renewable use, indicating that financial capacity is key to undertaking clean energy projects. As in the structural models, Mexican firms display lower renewable uptake than their Chilean peers,

**Table 4**  
Multiple linear mixed-effects regression results - Structural diversity (ISD).

	Model 1 (M1)		Model 2 (M2)		H
Intercept	< 0001***	(−3,82)	< 0001***	(−4,60)	
ISD	0004***	(1,16)			H1
Board size			0233	(0,08)	H1a
Independence			0109	(−0,89)	H1b
Ownership			1168	(0,13)	H1c
Regulation	0001***	(2,37)	0001***	(2,49)	Control
Company size	0021	(0,43)	0023**	(0,44)	Control
Leverage	0021**	(2,05)	0015**	(2,19)	Control
Country_Colombia	0600	(0,43)	0687	(−0,34)	Control
Country_México	< 0001***	(2,77)	< 0001***	(−3,24)	Control
Country_Perú	0539	(0,53)	0530	(−0,55)	Control
Industry_Retail trade	0885	(0,16)	0997	(−0,01)	Control
Industry_Transportation & Public Utilities	0557	(−0,44)	0601	(−0,40)	Control
Industry_Finance, Insurance, Real Estate	0002***	(1,75)	0010**	(1,50)	Control
Industry_Mining	0029**	(2,54)	0062*	(2,19)	Control
Industry_Wholesale Trade	0001***	(−1,93)	< 0001***	(−1,94)	Control
Industry_Services	0162	(1,71)	0157	(1,77)	Control
Industry_Agriculture, forestry, fishing	0844	(0,22)	0532	(0,75)	Control
R2 conditional	0,83		0,83		
R2 marginal	0,35		0,34		

\*, \*\* and \*\*\*, indicate significance at 10%, 5% and 1% levels, respectively.

a result consistent with cross-country policy assessments highlighting regulatory instability and enforcement gaps in Mexico relative to Chile and Peru (Mejía-Montero et al., 2023; Husted and de Sousa-Filho, 2019). At the industry level, mining again stands out as a green leader ( $p < 0.05$ ), driven by recent PPAs and pressure from international buyers. Finance, insurance, real estate also shows a significant positive effect, reflecting reputational exposure and easy access to clean power via PPAs or origin certificates. Wholesale trade, by contrast, records negative coefficients ( $p < 0.01$ ), likely due to scale constraints and limited space for on-site generation.

The marginal R<sup>2</sup> (0.34–0.35) indicates that demographic variables explain roughly one-third of the variability in renewable use, whereas the conditional R<sup>2</sup> (0.83–0.88) shows that adding random effects captures a substantial share of heterogeneity not accounted for by the observed predictors.

Viewed collectively, the results in Table 5 confirm that demographic diversity, especially female and foreign directors, strengthens corporate commitment to renewable energy, extending prior evidence for Pacific Alliance emerging markets. Managers aiming to speed up the energy transition should therefore prioritize inclusive, globalized boards able to mobilize knowledge, experience, and legitimacy with key stakeholders.

Several individual board attributes do not exhibit statistically significant effects on renewable energy adoption when considered in isolation, including board size, board independence, ownership concentration, female chairmanship, average tenure, and international education. This suggests that formal governance features or certain demographic traits have limited influence unless they are embedded within a broader and cohesive governance structure, particularly in contexts of uneven regulatory enforcement where “best practices” may become largely symbolic (Abreu et al., 2022; Zhang et al., 2021; Fakoya and Nakeng, 2019). In addition, low variability in some attributes may reduce statistical power. Overall, these findings reinforce the study’s central conclusion that individual board traits are insufficient to drive the corporate energy transition on their own, whereas diversity becomes effective when multiple structural and demographic dimensions operate jointly, as captured by the composite indices.

#### 4.3. Robustness checks and model validation

We assessed robustness using standard diagnostics: VIFs were all <10 (maximum 8), indicating no serious multicollinearity (Kutner et al., 2005); Breusch–Pagan tests did not reject homoscedasticity (p-values: M1=0.157, M2=0.167, M3=0.196 M4=0.273) (Breusch and Pagan,

**Table 5**  
Multiple linear mixed-effects regression results - Demographic diversity (IDD).

	Model 3 (M3)		Model 4 (M4)		H
Intercept	< 0001***	(-4,07)	< 0001***	(-10,44)	
IDD	< 0001***	(0,13)			H2
Female_directors			0039**	(1,54)	H2a
Female_Chair			0173	(0,55)	H2b
Tenure			0244	(0,05)	H2c
Age			0023**	(0,08)	H2d
Studies_abroad			0394	(0,57)	H2e
Foreign_director			< 0001***	(2,20)	H2f
Regulation	0003***	(2,22)	0007***	(2,35)	Control
Company_size	0036**	(0,40)	0036**	(0,46)	Control
Leverage	0020**	(2,07)	< 0001***	(3,25)	Control
Country_Colombia	0746	(-0,27)	0992	(-0,01)	Control
Country_México	< 0001***	(-2,58)	0001***	(-2,88)	Control
Country_Perú	0447	(-0,67)	0399	(-0,88)	Control
Industry_Retail trade	0852	(0,42)	0500	(0,93)	Control
Industry_Transportation & Public Utilities	0737	(-0,25)	0630	(-0,47)	Control
Industry_Finance, Insurance, Real Estate	0007***	(1,56)	0017**	(1,63)	Control
Industry_Mining	0043**	(2,39)	0043**	(2,79)	Control
Industry_Wholesale Trade	0002***	(-1,93)	0004***	(-2,07)	Control
Industry_Services	0243	(1,45)	0266	(1,59)	Control
Industry_Agriculture, foresting, fishing	0698	(0,45)	0538	(0,84)	Control
R2 conditional	0,83		0,88		
R2 marginal	0,34		0,35		

\*, \*\* and \*\*\*, indicate significance at 10%, 5% and 1% levels, respectively.

Non-significant hypotheses and their implications.

1979); all Cook’s distances were <4/n, ruling out influential observations; and Q–Q plots plus formal tests showed no material departures from residual normality (Gujarati and Porter, 2009). Collectively, model assumptions hold and the findings are robust.

4.4. Sensitivity analysis

To test the robustness of our findings, we estimated adjusted marginal means (estimated marginal means, EMMs) with the emmeans package in R (Lenth, 2025). The procedure, based on the Kenward Roger degrees of freedom method and Tukey p-value adjustment, compares countries and industries while holding the model’s other covariates constant (Searle et al., 1980).

This technique was applied to the two key indices:

- H1 – Structural diversity (ISD, Model 1)
- H2 – Demographic diversity (IDD, Model 3)

The results reported in Table 6 reveal a consistent country-level pattern. Under Model 1 (ISD), firms headquartered in Mexico display significantly lower adjusted renewable energy use than firms in Chile and Peru, as evidenced by the significant Chile–Mexico ( $p < 0.01$ ) and Mexico–Peru ( $p < 0.05$ ) contrasts. No statistically significant differences are observed among Chile, Colombia, and Peru, indicating relatively homogeneous outcomes once structural board diversity and other covariates are considered.

A similar pattern emerges under Model 3 (IDD). Mexican firms again exhibit significantly lower adjusted renewable energy use compared to Chile ( $p < 0.01$ ), while the difference between Mexico and Peru is weaker and only marginally significant after Tukey adjustment ( $p < 0.10$ ). As in the structural diversity model, no significant differences are detected among Chile, Colombia, and Peru.

Taken together, these results reinforce the study’s central conclusion: board diversity is positively associated with renewable energy use, but its effectiveness is conditioned by the institutional context. Despite facing comparatively ambitious regulatory targets, Mexican firms continue to lag behind their regional peers, consistent with earlier evidence on delays in the implementation of Clean Energy Certificates, grid constraints, and regulatory uncertainty (Mejía-Montero et al., 2023). Importantly, these country-level differences persist after controlling for

**Table 6**  
Country EMMs & significant tukey contrasts.

País	EMM (SE)	95% CI	Reference Contrast	Δ EMM	Adj. P	Sig.
<b>H1 – ISD (Mod 1)</b>						
Chile	-0.64 (0.45)	-1.55; 0.26	Chile–México	+2.77	0.0012	***
Colombia	-1.07 (0.86)	-2.80; 0.66	—	—	—	—
México	-3.41 (0.48)	-4.38; -2.45	México–Perú	-2.24	0.0215	**
Perú	-1.17 (0.70)	-2.57; 0.23	—	—	—	—
<b>H2 – IDD (Mod 3)</b>						
Chile	-0.68 (0.46)	-1.60; 0.24	Chile–México	+2.58	0.0033	***
Colombia	-0.95 (0.88)	-2.72; 0.82	—	—	—	—
México	-3.26 (0.49)	-4.24; -2.28	México–Perú	-1.90	0.0715	*
Perú	-1.35 (0.71)	-2.78; 0.07	—	—	—	—

\*, \*\* and \*\*\*, indicate significance at 10%, 5% and 1% levels, respectively.

EMM = estimated marginal mean; SE = standard error.

\* Only pairwise differences that remain significant after Tukey adjustment are reported; non-significant contrasts are omitted for brevity.

firm characteristics and are further examined through industry-level analyses, reducing concerns that they merely reflect differences in sectoral composition. This suggests that internal governance mechanisms, while important, require a stable and credible regulatory environment to fully translate into higher renewable energy adoption.

To further explore heterogeneity in the results, we estimated industry-level adjusted marginal means for the models capturing structural board diversity (M1) and demographic board diversity (M3) in Table 7. This analysis allows us to assess whether the observed country-level patterns are robust within relatively homogeneous industries, thereby addressing potential confounding effects related to sectoral energy intensity.

In both models, energy intensive sectors such as Manufacturing,

**Table 7**  
Industry EMMs & significant tukey contrasts.

Industry	EMM (SE)	95% CI	Reference Contrast	Δ EMM	Adj. P	Sig.
<b>H1 – ISD (Model 1)</b>						
Manufacturing	-2.08 (0.36)	-2.81; -1.35	Manufacturing–Finance, Insurance, Real Estate	-1.76	0.0415	**
Retail trade	-1.92 (1.14)	-4.21; 0.38	—	—	—	—
Transportation & Public Utilities	-2.52 (0.61)	-3.73; -1.31	—	—	—	—
Finance, Insurance, Real Estate	-0.33 (0.50)	-1.33; 0.68	Finance, Insurance, Real Estate–Wholesale Trade	+3.68	< 0.0001	***
Mining	0.47 (1.12)	-1.79; 2.72	Mining–Wholesale Trade	+4.47	0.0099	***
Wholesale Trade	-4.01 (0.54)	-5.08; -2.93	—	—	—	—
Services	-0.37 (1.14)	-2.65; 1.91	—	—	—	—
Agriculture, forestry, fishing	-1.86 (1.13)	-4.13; 0.41	—	—	—	—
<b>H2 – IDD (Model 3)</b>						
Manufacturing	-2.07 (0.37)	-2.81; -1.33	Manufacturing–Wholesale Trade	+1.93	0.0323	**
Retail trade	-1.65 (1.17)	-4.00; 0.70	—	—	—	—
Transportation & Public Utilities	-2.33 (0.62)	-3.57; -1.09	—	—	—	—
Finance, Insurance, Real Estate	-0.51 (0.51)	-1.54; 0.51	Finance, Insurance, Real Estate–Wholesale Trade	+3.49	0.0001	***
Mining	0.32 (1.14)	-1.97; 2.61	Mining–Wholesale Trade	+4.32	0.0175	**
Wholesale Trade	-4.00 (0.55)	-5.10; -2.90	—	—	—	—
Services	-0.63 (1.16)	-2.94; 1.70	—	—	—	—
Agriculture, forestry, fishing	-1.62 (1.15)	-3.94; 0.69	—	—	—	—

\*, \*\* and \*\*\*, indicate significance at 10%, 5% and 1% levels, respectively.

EMM = estimated marginal mean; SE = standard error.

\* Only pairwise differences that remain significant after Tukey adjustment are reported; non-significant contrasts are omitted for brevity.

Mining, and Wholesale Trade display significantly lower adjusted renewable energy use compared to less energy-intensive and more reputation-sensitive sectors, particularly Finance, Insurance, Real Estate and Services, which exhibit higher adjusted means. Transportation & Public Utilities and Retail Trade occupy intermediate positions, reflecting mixed regulatory exposure and operational constraints.

Overall, these findings suggest that board diversity is more effective in industries with greater strategic flexibility and easier access to clean electricity procurement mechanisms, such as power purchase agreements or certificates of origin. By showing that the main relationships hold across countries and within industries, the sensitivity analysis strengthens the interpretation of the results and supports the view that the findings are not driven solely by country-specific or sector-specific reporting patterns. This industry-level evidence reinforces the main results by showing that governance mechanisms interact with industry-specific energy intensity and investment constraints in shaping firms' renewable energy adoption.

## 5. Discussion

This study offers four interrelated theoretical insights that advance the discourse on corporate governance and sustainability. First, by showing that structural board diversity is positively linked to firms' renewable energy intensity (i.e., the share of renewables in total energy consumption), the study deepens agency theory, demonstrating that the combination of an adequately sized board, director independence, and balanced ownership strengthens monitoring mechanisms and lowers agency costs in long horizon environmental investments (Eisenhardt, 1989; Fama and Jensen, 1983). Second, the results extend resource dependence theory to the energy transition context: the importance of the IDD and, in particular, female representations and foreign directors, confirms that heterogeneous boards act as boundary spanners who bring knowledge, networks, and legitimacy to the adoption of clean technologies (Pfeffer and Salancik, 2015; Hillman et al., 2000). Third, the study integrates internal and external governance frameworks: the persistent positive role of mandatory regulation alongside board diversity supports the combined logic of stakeholder theory and institutional theory, showing that the effectiveness of internal mechanisms depends on coercive, normative, and cognitive pressures in the external environment (Freeman, 1984; DiMaggio and Powell, 1983). Finally, by focusing on firms in the Pacific Alliance, the research offers a context-specific perspective for Latin American emerging markets, demonstrating that board diversity can mitigate institutional weakness and catalyse

renewable-energy adoption even where regulatory enforcement is inconsistent (Abreu et al., 2022; Correa-García et al., 2020; Husted and de Sousa-Filho, 2019). Importantly, our post-estimation analyses indicate that cross-country differences persist after adjustment, suggesting that institutional and policy conditions meaningfully shape how governance translates into renewable energy outcomes.

This research also contributes to the governance and sustainability literature in three principal respects. First, it introduces novel empirical evidence for the Pacific Alliance, an underexplored region in board diversity and energy transition research. Most prior work focuses on North America, Europe, or Asia, so our findings broaden the comparative agenda by placing the debate within emerging economies that operate under heterogeneous regulatory frameworks (Abreu et al., 2022; Husted and de Sousa-Filho, 2019). Second, it adopts a metric centred on firms' renewable energy intensity (share of renewable energy in total energy use), a dependent variable directly tied to SDG 7, rather than relying on aggregate environmental scores such as ESG ratings. This approach captures corporate decarbonisation decisions more precisely (Atif et al., 2021). Finally, the study develops and validates two composite diversity indices (ISD and IDD) that integrate structural and demographic board dimensions through multivariate distance and tercile stratification methods (Hafsi and Turgut, 2013). In practical terms, these indices summarise multiple board attributes into a single measure, capturing overall board heterogeneity while reducing model complexity and multicollinearity. These indices move beyond traditional univariate metrics and offer researchers and practitioners a replicable tool for assessing board pluralism in emerging markets.

These contributions carry direct practical implications. For firms, expanding board diversity constitutes a practical mechanism for enhancing strategic decision quality and accelerating the corporate adoption of clean energy; it is also advisable to set up a sustainability committee and tie part of executives' bonuses to renewable energy targets. Regulators can speed the transition by toughening diversity requirements, mandating transparent disclosure of board composition and energy use, and aligning these rules with national decarbonisation goals. For investors, board diversity is an early signal of environmental commitment; incorporating it into ESG analysis and engaging with companies whose boards remain homogeneous can drive real progress. Lastly, sustainability officers and consultants can contribute by designing tailored training programs for directors and devising rigorous yet accessible metrics that allow boards to monitor performance and make evidence-based decisions. The industry-level sensitivity analysis further suggests that governance levers may be particularly effective in

sectors with greater strategic flexibility and access to renewable procurement mechanisms (e.g., PPAs or certificates of origin), whereas highly energy-constrained sectors may require stronger policy and infrastructure support to unlock similar progress.

Despite the robustness of the results, several limitations warrant consideration. Although the analysis covers five consecutive years (2020–2024), board characteristics tend to evolve gradually, which may limit within-firm temporal variation and increase reliance on cross-sectional differences across firms; nevertheless, this approach is appropriate for the Latin American context, characterized by uneven and frequently changing regulatory environments.

Moreover, the 2020–2024 window encompasses COVID-19 and post-pandemic disruptions that may have affected energy use patterns, ESG priorities, and policy implementation, potentially making this period atypical. In addition, low variability in certain board attributes (e.g., female chairmanship or international education) may reduce statistical power (Gelman et al., 2021; Kutner et al., 2005), while the use of composite indices with fixed and tertile-based weights may mask non-linear effects or interaction patterns (Ding and Wang, 2025; Hafsi and Turgut, 2013). Further, renewable energy and total energy data were manually extracted from corporate disclosures and harmonized into kWh; differences in reporting practices may introduce measurement noise and disclosure bias, although our country- and industry-level sensitivity analyses help mitigate concerns that results are driven solely by reporting intensity. Finally, because the sample is restricted to firms included in the S&P MILA Pacific Alliance Index, large and highly visible companies with relatively advanced governance practices, the findings should be interpreted as representative of leading listed firms and may not be directly generalizable to smaller or private firms in Latin American markets.

## 6. Conclusions

Empirical evidence confirms that a diverse board of directors, especially in demographic terms, but also in structural composition, is positively associated with higher renewable energy intensity (i.e., a larger share of renewable sources within total energy consumption) among firms in the Pacific Alliance. Companies with well-balanced boards report higher levels of clean energy use. These results indicate that board diversity is not merely a symbolic governance feature but a strategic internal mechanism that supports concrete clean-energy decisions and long-term decarbonisation efforts.

Country-level differences further underscore the importance of the institutional environment. Even under ambitious regulatory targets, firms operating in contexts marked by regulatory instability, delayed implementation, or infrastructure constraints display lower adjusted renewable energy use. This highlights that the effectiveness of internal governance mechanisms depends on the credibility and stability of external regulatory frameworks.

From a practical perspective, the findings suggest that appointing diverse directors must be accompanied by real influence over strategic energy decisions to be effective. For policymakers, the results emphasise the need to align board-level governance reforms with stable, transparent energy policies and adequate infrastructure investment, ensuring that good governance translates into measurable environmental outcomes.

Overall, this study demonstrates that aligning board composition with sustainability challenges, while accounting for institutional constraints, can accelerate firms' contributions to the energy transition, offering relevant insights for emerging markets and supporting progress toward SDG 7 and broader climate action goals.

## CRedit authorship contribution statement

**Ivette Núñez-Laguna:** Writing – original draft, Visualization, Validation, Supervision, Software, Project administration, Methodology,

Investigation, Formal analysis, Data curation, Conceptualization. **María Antonia García-Benau:** Writing – review & editing, Supervision, Resources, Methodology, Investigation, Funding acquisition, Conceptualization. **Nicolás Gambetta:** Writing – review & editing, Validation, Supervision, Investigation, Formal analysis, Conceptualization. **Marco Giuliani:** Writing – review & editing, Validation, Supervision.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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## Data availability

Data will be made available on request.

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