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Potential for eco-innovation: evidence from the copper sector and avenues for future research

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Abstract

The aim of this study was examined how market factors influence dynamics of an industry pivotal to the energy transition and global sustainability, the copper sector. It was sought to bring evidence regarding how such dynamics may shape the participation of companies in the sector, and where Eco Innovation (EI) can be meaningfully fostered and further investigated. First, global data were analysed using the decision tree technique which enables the identification of hierarchical patterns and variable interactions. Following this, a regression model was fitted to analyse in a greater depth data from the world largest copper producer, Chile. Results demonstrate that shifts in the copper's sector dynamics have the potential to open new avenues for business development and expansion, where future EI behaviours can be fostered and investigated. Additionally, given the lack of empirical evidence in the field of EI, particularly from critical sectors with the potential to address sustainability challenges, this study proposes an agenda for future research endeavours.

Keywords: Eco Innovation, business possibilities, sustainability, electromobility, copper industry

Introduction

Sustainability and climate change are among the most pressing concerns in the international community agenda. Record levels of greenhouse gases were observed in 2023, and data indicate that they continued to rise in 2024, contributing to cause global damage such as wildfires, flooding, and hot and cold waves (Kennedy et al., 2024).

Climate change presents significant challenges for society as it relates to food and water security, human health, and impact on the economy in general (IPCC, 2023). These concerns are even more pronounced when reviewing the progress report on the Sustainable Development Goals (SDGs) established by the United Nations (UN) for a more sustainable world. The report reveals that only 17% of the SDG targets are on track, nearly half showing minimal or moderate progress, with over a third of this progress stalled or even regressed (UNPD, 2024).

At COP 28 in Dubai (2023), 133 countries committed to tripling global renewable power capacity and doubling energy efficiency improvements by 2030, supporting United Nations Framework Convention on Climate Change (UNFCCC) efforts (IRENA, 2024). They also pledged to pursue an energy transition aligned with the Paris Agreement's 1.5°C target, emphasizing scalable, low-cost renewables and efficiency measures as key solutions (IRENA, 2024).

Entrepreneurship and innovation are vital for tackling climate change, promoting sustainable industries, and driving global development. Entrepreneurship fosters job creation and competitiveness (Naudé, 2008), while innovation is central to a just and secure energy transition (IRENA, 2025). The rise of electromobility, particularly in the Electric Vehicle (EV) sector, has spurred increased demand for metals like copper and lithium since 2015 (Jones et al., 2020).

In this context, and considering the challenges mentioned before, Eco Innovation (EI) which according to Rennings (2000), encompasses all actions taken by relevant stakeholders (e.g. firms, politicians, associations, and private households) to develop, implement, or introduce new ideas, behaviours, products, and processes that help reduce environmental impacts or achieve ecologically focused sustainability goals, plays a key role. Rennings (2000) argues that the distinguishing feature of innovations aimed at sustainability is their ability to reduce environmental burdens.

Since Renning's (2000) seminal work, EI literature has advanced, highlighting both economic and environmental benefits over other innovation types (Horbach, 2008). Pollution-reducing innovations have helped firms enhance their image, access new markets, and gain competitive advantages (Chen, 2008). EI's complexity stems from distinct motivations and externalities—knowledge spillovers that can hinder investment or be underutilized—though open innovation may help address these challenges (Chistov et al., 2021). Evidence on market conditions that foster EI remains crucial (Lopez-Perez et al., 2024).

Studies have identified key EI drivers (e.g., Lopez-Perez et al., 2024; Fernandez et al., 2021; Horbach et al., 2012) and barriers (Lopez-Perez et al., 2024; Kiefer et al., 2018), with four main EI types: product, process, organizational, and marketing (Lopez-Perez et al., 2024). Determinants include supply, demand, and institutional factors (Horbach, 2008), later expanded to firm-specific, technological, market, and regulatory influences (Horbach et al., 2012).

Despite growing scholarly interest (Perez et al., 2024), gaps persist—particularly in linking EI to firm performance and reconciling inconsistent empirical findings (Passaro et al., 2022). Research remains skewed toward large firms with R&D capacity (Saez-Martínez et al., 2016), and is concentrated in developed countries, leaving developing

contexts underexplored (Fernandez et al., 2021; Lopez-Perez et al., 2024; Passaro et al., 2022).

Considering the scenario outlined thus far, it is evident that further empirical evidence is needed to advance the field of EI studies. In particular, the research gaps should not only be acknowledged but addressed through investigations situated in contexts where EI can be amplified. Strategic markets aligned with the goals of the electromobility transition (IRENA, 2024; 2025) offer such potential. These contexts—shaped by specific market conditions (Horbach, 2008)—may provide enhanced opportunities for firms to engage. Consequently, research can be meaningfully explored by examining how factors such as market conditions may facilitate the participation of companies in markets conducive to EI development.

Thus, the aim of this study is to examine how market factors influence dynamics of an industry pivotal to the energy transition and global sustainability, the copper sector. It is sought to bring evidence regarding how such dynamics may shape the participation of companies in the sector, and where EI can be meaningfully fostered. Shifts in these dynamics may affect the involvement of companies, potentially generating new avenues for business development and expansion. Through such engagement, future EI behaviours may be fostered in sectors that are pivotal to sustainability and to meeting the increasing demand for electromobility (IRENA, 2025), demonstrating a need to be investigated.

This study shed light on how market dynamics can shape the participation of new entry companies into crucial markets for sustainability. It also guides new research efforts by delivering a research agenda that covers topics with lack of evidence or unaddressed ones.

Eco Innovation

EI is defined as all actions taken by relevant stakeholders as firms, politicians, associations, and private households to develop, implement, or introduce new ideas, behaviours, products, and processes that help to reduce environmental impacts or achieve ecologically focused sustainability goals (Rennings, 2000). Another definition is the one given by the European Commission (2024), which defines EI as any innovation that reduces impacts on the environment, increases resilience to environmental pressures or uses natural resources more efficiently.

Among the factors identified in the literature as driving EI, Lopez-Perez et al. (2024) argue that regulatory pressure is one of the main drivers of EI. Fernandez et al. (2021) state that market factors and public support would act as drivers with the caveat that only with a weak effect. For Kiefer et al. (2019), an EI-friendly corporate culture, technology-push and market-pull, and internal financing resources are drivers of EI.

Triguero et al. (2013) argue that entrepreneurs who value collaboration with research institutions, government agencies, and universities—and who recognize the growing market demand for green products—tend to be more proactive across all forms of eco-innovation. Additionally, Saez-Martinez et al. (2016) inform that companies that actively seek out new opportunities and maintain ongoing partnerships with market stakeholders are more likely to foster EI.

Interestingly, regarding partnerships, unlike Martinez et al. (2016), for Kiefer et al. (2019), cooperation, alongside with organizational learning, an International Organization for Standardization (ISO) ecological certification, and technological path dependency are barriers of EI. Still regarding ISO certifications, Cuerva et al. (2014) argue that SMEs that prioritize quality and choose to implement a standardized Quality Management System (e.g. ISO 9000) tend to be more motivated to pursue green innovation. Put differently, managers who emphasize quality often demonstrate a

heightened awareness of environmental issues and recognize the importance of adopting EI. Lopez-Perez et al. (2024) also identified barriers of EI, specifically regarding SMEs, among them, capital, government support, and effective legislation. Regarding the types of EI, Lopez-Perez et al. (2024) inform four main types: product EI; process EI; organizational EI and marketing EI.

Therefore, if we summarize drivers for EI, according to Horbach et al. (2012), there are four groups in which those factors concentrate in. These factors are firm-specific factors, technology, market, and regulation. Building on the preceding discussion and the potential for new business opportunities, this study will concentrate on one of the four categories of drivers for EI identified in the literature, the market dynamics (Horbach et al. (2012; Lopez-Perez et al., 2024; Fernandez et al., 2021), and operationalized its analysis trough the variables investment, production and export (in the regression model). Thus, the following hypothesis are established:

H1: Production has a significant effect on investment dynamics in the Chilean copper market.

H2: Export has a significant effect on investment dynamics in the Chilean copper market.

H3: The interaction between Production and Time has a significant effect on investment dynamics in the Chilean copper market.

H4: The interaction between Export and Time has a significant effect on investment dynamics in the Chilean copper market.

The analysis will be situated within a key industry that plays a pivotal role in the energy transition and sustainability agenda, the copper industry.

Context of the study

Given the context of global concern about sustainability (Kennedy et al., 2024; IPCC, 2023) with the challenges it imposes and the opportunities for innovation to contribute to innovative sustainable solutions towards global energetic transition (IRENA, 2025), certain markets stand out. Markets with resources that prove to be strategic and highly relevant to the aimed energetic transition (IRENA, 2025) are the ones that produce goods and inputs for the advancement in electromobility. Two markets worth mentioning that contribute to that regard are the copper and lithium ones. Concerning the importance and properties of copper and lithium, the International Copper Study Group (ICSG) reports that copper is a malleable and ductile metallic element that is an excellent conductor of heat and electricity. Also remarkable is its corrosion resistant and antimicrobial property (ICSG, 2025).

As for lithium, according to Tarascon (2010), the physical, chemical and electrochemical properties of lithium make it attractive to many fields. One relevant use of lithium is in energy storage (Manthiram et al., 2013; Li et al., 2018) and lithium-ion batteries are now the technology of choice for advancing renewable energy systems and EV. In fact, according to Chilean Copper Commission (Cochilco) (2024b), The lithium exploration budget rose by 30% in 2024 compared to 2023, making it the only metal among those used in primary batteries—such as nickel and cobalt—to record an increase this year. Certain regions of the world possess vast reserves and production capacity of copper and lithium. This characteristic makes these regions particularly relevant for promoting EI by enabling, for example, open innovation approaches among companies (Valdez-Juárez & Castillo-Vergara, 2021). One relevant region is South America, more specifically Chile, the world largest copper producer (Cochilco, 2025), which also holds large reserves of lithium. Another region is Oceania, specifically Australia, the world largest producer of

lithium (Cochilco, 2024b). Both regions stand out when it comes to analyse aspects as business opportunities and the participation of companies given market conditions.
In that regard, according to Cochilco (2024b), Junior companies have remained the key drivers of lithium exploration, as well as of metals generally used in battery manufacturing. Australia, Canada, and Latin America continue to be the leading hubs for exploration, a trend attributed to their geological potential and the strong presence of junior firms. It is in contexts like the Chilean and Australian ores production-copper and lithium specifically-, where EI can be potentialized given the already mentioned contribution to sustainability, for example, when it comes to energy transition and electromobility (IRENA, 2025).
Fernandez et al. (2021) carried out a study in the Chilean context to analyse the drivers of EI and considered the country as a developing one. Fernandez et al. (2021) argue that most studies on EI have been carried out in developed countries. However, unlike Fernandez et al. (2021), the World Bank considers Chile a high-income country (World Bank, 2025c).
The World Bank country classification assigns the world's economies to four income groups: low (<1,145), lower-middle (1,146-4,515), upper-middle (4,516-14,005), and high (>14,005). The classifications are updated each year on July 1, based on the Gross National Income (GNI) per capita of the previous calendar year. GNI measures are expressed in United States dollars using conversion factors derived according to the Atlas Method[1], which in its current form was introduced in 1989. The World Bank's income classification aims to reflect a country's level of development, drawing on Atlas GNI per capita as a broadly available indicator of economic capacity (World Bank, 2025b).
Therefore, even though and according to the World Bank classification, Chile it is not considered a developing country, but a high incomes one, this study contributes not just globally to the areas hereby addressed, but also to the regional context of South America where, according to this new World Bank classification, most of the countries belong to the group of low, lower-middle or upper-middle level countries (World Bank, 2025c) and where a vast mining production is developed (Liu et al., 2025).
Considering the international commitment to triple global renewable energy capacity and double the average annual rate of energy efficiency improvements by 2030 (IRENA, 2024), the strategic relevance of the targeted markets becomes increasingly pronounced. This growing importance highlights the urgency of generating empirical evidence from these contexts to advance the field of EI. Accordingly, this study examines the evolution of market conditions over time, with a particular emphasis on the copper industry—a sector that plays a pivotal role in the energy transition and sustainability agenda.

Methodological aspects

This study examines, at the sector level, critical dimensions of an industry pivotal to the energy transition and global sustainability, and from where empirical evidence informing

[1] The World Bank's official estimates of the size of economies and country classifications by income level are based on Gross National Income (GNI) per capita. For cross-national comparisons, estimates are converted from local currency units (LCU) to current U.S. dollars using the Atlas method, referring to a former World Bank publication called the Atlas of Global Development. The Atlas method smooths exchange rate fluctuations using a three-year moving average, price-adjusted conversion factor. The USD estimate of GNI per capita is derived by applying the Atlas conversion factor to estimates measured in LCU. For more details, see the detailed methodology page.

research on EI is needed: the copper sector. We applied the following methodological approach given the lack of empirical evidence from strategic markets aligned with the goals of the electromobility transition (IRENA, 2024; 2025), and focusing in one of the determinants of EI informed in the literature, that is market conditions (Horbach, 2008). It begins with an exploratory approach analysing global market demand, prices, and export volumes to assess whether—and how—these factors influence production dynamics at the international level. These insights form the basis for considering how such dynamics may shape the participation of companies in markets central to sustainability and the rising demand for electromobility, where EI can be meaningfully fostered.

To explore these relationships, international copper industry data were analysed using a decision tree methodology (Breiman et al., 2017), which enables the identification of hierarchical patterns and variable interactions by recursively partitioning the dataset into subsets based on the most significant predictors. Following this, now with a confirmatory approach, a linear regression model was fitted (Hair et al., 2009). This regression model was applied in a greater depth to evaluate the significance of key variables (Investment, Production and Export) within the Chilean copper industry-the world largest copper producer. More specifically, the study seeks to highlight the potential for expansion and entry of new businesses in industries like copper, given its importance for advancing electromobility and achieving sustainability goals, and where EI can be fostered and further investigated.

Data collection

For the initial analysis involving the decision tree approach, available data on global copper demand, production, exports, and prices from 2014 to 2024 were collected from the Chilean Commission of Copper (Cochilco). This dataset enabled the identification of key patterns and predictors influencing global production dynamics. Additionally, to evaluate variable relationships and conduct a deeper analysis of the world's largest copper producer, supplementary available data on Chilean copper production, exports, and investment spanning 2004 to 2024 were also obtained (Cochilco, 2025). This country-specific dataset supported the development of a regression model aiming at capturing investment dynamics within Chile's copper sector. Together, this dual-layered dataset supports an evidence-based exploration of potential avenues for company participation in markets central to sustainability and electromobility, where EI can be strategically fostered.

Tables 1 shows the first model with the decision tree technique. Tables 2 shows the regression model and its variables.

Table 1. Decision tree model

Variable	Description	Type	Source
Yearly world production	World yearly copper production from 2014 to 2024	Dependent	Cochilco
Yearly world demand	Yearly copper demand from 2014 to 2024	Independent	Cochilco
Yearly world price	Yearly copper price from 2014 to 2024	Independent	Cochilco
Yerly world export	Yearly copper export from 2014 to 2024	Independent	Cochilco
Year	From 2014 to 2024	Independent	Cochilco

Source: authors

Table 2. Regression model

Variable	Description	Type	Source
Yearly Chilean investment	Chilean yearly copper investment from 2004 to 2024	Dependent	Cochilco
Yearly Chilean production	Chilean yearly copper production from 2004 to 2024	Independent	Cochilco
Yearly Chilean export	Chilean yearly copper export from 2004 to 2024	Independent	Cochilco

Source: authors

Data analysis

This study first employs a decision tree regression model to explore the factors influencing copper production over an 11-year period. The model was constructed using the rpart algorithm in R, with Production as the dependent variable and Demand, Price, Export, and Year as predictors. The tree was grown using a low complexity parameter (cp = 0.001) and minimal constraints on node size (minsplit = 2, minbucket = 1) to allow for detailed segmentation of the data.

Following this exploratory step, in a deeper analysis focused on the world's largest copper-producing country, Chile, the relationship and significance among variables such as Investment, Production, and Export was evaluated using a regression model. This country-specific approach aimed to bring evidence of business expansion potential driven by investment dynamics in this strategic market.

Results

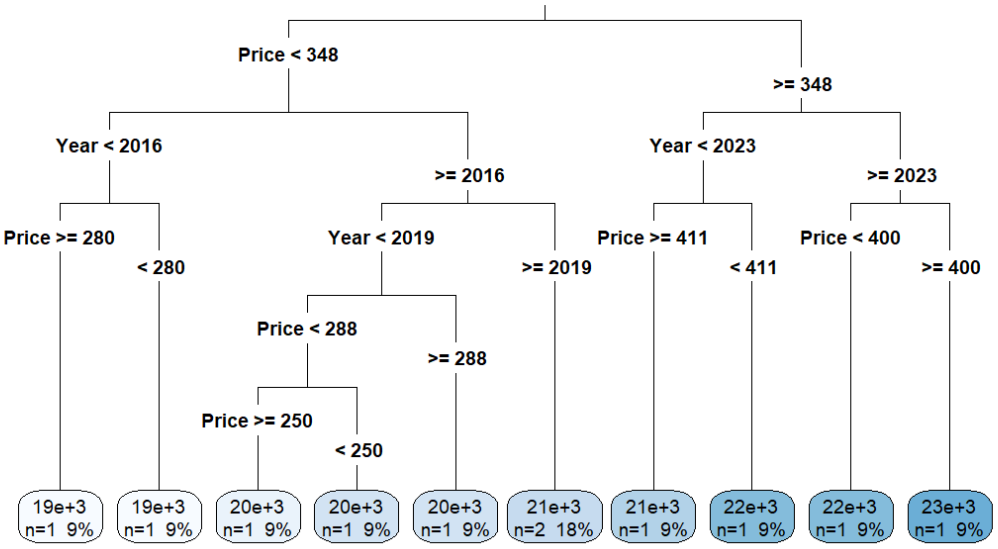
Decision Tree and Regression results

To explore the underlying structure and no linear relationships of copper production in relation to economic indicators, a decision tree model was applied using recursive partitioning. The model incorporated four predictors—Price, Year, Demand, and Export—and was fitted using the ANOVA method to accommodate the continuous nature of the response variable. A low complexity parameter (cp = 0.001) was selected to enable deep splitting and detailed segmentation of the data.

The tree revealed meaningful patterns. The initial split occurred at Price < 347.9, suggesting that price is a primary driver in differentiating production levels. Subsequent splits involved the variable Year, indicating that temporal factors play a significant role. The model's structure highlighted several thresholds—such as Year < 2020.5, that segment the data into increasingly homogeneous groups with respect to production output.

Overall, the decision tree served as a valuable exploratory tool, revealing potential nonlinear relationships and interaction effects among predictors. Its visual and hierarchical structure facilitated intuitive understanding of how copper production may respond to shifts in price and time (Figure 1).

Figure 1. Decision Tree



Source: authors

These findings provided a foundation for more robust and deeper modelling through a regression approach. Therefore, the analysis turned to a focused examination of Chile, the world's leading copper producer. Leveraging updated national data (2004-2024) from Cochilco (2025), a regression model was developed to assess investment dynamics within the Chilean context. This country-specific analysis offered deeper insights into the structural factors influencing copper output and provides valuable information for reflecting on the potential expansion of existing operations or the entry of new firms into the Chilean copper market. The model was fitted using available data on Investment, Export, Production, and Year, including their interaction terms so that bring evidence of business expansion potential driven by investment dynamics in this strategic market (See Table 3).

Table 3. Regression results

Model	Adjusted R^2	
	83,18%	
Variable	Standardized coefficients	P-value
Production	0.80157	< 0.0001
Export	-0.92754	< 0.0001
Export*Year	0.62244	< 0.001
Production*Year	-0.90869	< 0.0001

Source: authors

The model demonstrated high explanatory power, with an adjusted R-squared of 0.8318, indicating that over 83% of the variance in investment levels is explained by the included predictors. All coefficients were statistically significant, highlighting the relevance of both main effects and interactions. Production had a strong positive effect (Standardized coefficient = 0.80157, $p < 0.0001$), suggesting that higher output is closely tied to increased investment.

Export showed a negative main effect (Standardized coefficient = -0.92754, $p < 0.0001$), but its interaction with Year was positive (Standardized coefficient = 0.62244, $p < 0.001$),

indicating that the influence of exports on investment has grown over time. The interaction between Year and Production was negative (Estimate = −0.90869, $p < 0.0001$), suggesting diminishing marginal returns on investment from production as time progresses. Additionally, the model's F-statistic of 19.8 ($p < 0.00001$) confirms overall significance. Also, diagnostic checks confirmed that the model satisfies the assumptions of linear regression (Hair et al., 2009).

Additionally, given the nature of data, endogeneity was evaluated through Hausman's test (Ullah et al., 2018). Based on a comparison between models using Ordinal Least Square (OLS) and Instrumental Variable (IV) approaches, no strong evidence of endogeneity in the relationship between Production and Investment was found. The OLS model yielded statistically significant coefficients for all terms, including Production (estimate = 2,429; $p = 0.0350$), Year (estimate = 6,885; $p = 0.0275$), and the interaction Production:Year (estimate = –1.205; $p = 0.0350$). It also achieved an adjusted R-squared of 0.5731 and a residual standard error of 1,841. In contrast, the IV model—using Export as an instrument for Production—produced weaker and statistically insignificant coefficients: Production (estimate = 1,252; $p = 0.438$), Year (estimate = 3,778; $p = 0.385$), and Production:Year (estimate = –0.6237; $p = 0.436$), with a lower adjusted R-squared of 0.418 and a higher residual standard error of 2,149.

Also, to better assess the regression results, the following conditions were verified: i) absence of multicollinearity problems between predictors, by the Variance Inflation Factor (VIF < 10); ii) normality of residuals, by the Shapiro-Wilk test (p-value = 0.8588); iii) absence of influential values in the residuals, by the Cook distance (CD < |1|); iv) homoscedasticity of residuals, by the Breusch-Pagan test (p-value = 0.3291); and v) independence of residuals, by the Breusch-Godfrey test (p-value = 0.9009). The data were processed in the R software (R Core Team, 2022).

Discussion and conclusions

This study aimed to provide empirical evidence on how market dynamics within the copper sector can inform companies' entry possibilities—acknowledging that the copper sector is an essential industry for advancing on energy transition and sustainability goals. Furthermore, the study sought to demonstrate that shifts in this sector's dynamics could potentially open new avenues for business development and expansion. Horbach et al. (2012) argue that one of the determinants for EI is the dynamic of the market. Precisely, in this study it was possible to confirm that as the market grows, it may attract new entrants, and we understand future EI behaviours can be fostered within a sector pivotal to sustainability and the rising demand for electromobility (IRENA, 2025). Indeed, it is in sectors like copper, given their critical role in electromobility and sustainability objectives, where EI can and should be both encouraged and further investigated.

Moreover, it was confirmed that changes in copper production dynamics, positively affect investments in that sector and that when analysing the interaction of production and time, as well as exports and time, significant impacts are observed. More specifically, as investment is positively affected, new business possibilities can be created. Therefore, this study contributes to the field of EI bringing evidence regarding the unexplored context of copper sector when it comes to EI and may driving new efforts on that direction regarding other contexts.

The first model processed in this study—a decision tree built using global data—identified Price as the primary factor influencing copper production, followed by year-based thresholds. These findings highlight market dynamics that may affect the entry of new companies into the copper industry. Building on these insights and the underlying

logic of factors driving sectoral expansion, a second, and more targeted model was subsequently developed.

This second model aimed to assess how investment is influenced by sectoral dynamics, using Export, Production, and Year as predictors. The model exhibited a strong positive effect on investment (H1 supported), indicating its central role in driving sectoral growth. In contrast, although significant, Export demonstrated a negative main effect (H2 supported), with its influence increasing over the time, that is, its interaction with time (H3 supported). The interaction between Year and Production, also had a significant effect on investment (H4 supported), suggesting diminishing returns and implying that the impact of production on investment may taper as the sector matures.

These results suggest that the dynamics of the copper sector can significantly influence the entry of new companies. It is precisely within this phase of expansion that EI should be fostered and further investigated, given the sector's critical role in advancing global sustainability and electromobility objectives.

Again, EI is understood as all actions taken by relevant stakeholders to develop, implement, or introduce new ideas, behaviours, products, and processes that help to reduce environmental impacts or achieve ecologically focused sustainability goals (Rennings, 2000).

To the best of our knowledge, no published studies have specifically addressed the topic of EI within the copper sector as we did. This highlights a critical gap in the literature and underscores the need to better understand how EI is fostered in this industry—potentially through public policies, as observed in other sectors. For instance, Ortiz-Rojo et al. (in press) evaluated the impact of a national public policy aimed at promoting exports among companies. Their findings offer valuable theoretical and practical contributions for both academic research and policymaking.

Likewise, higher education plays a vital role in fostering EI. Contributions from the educational sector extend beyond the formal teaching responsibilities of higher education institutions (HEI) to include the active engagement of their academics (Ortiz-Rojo & Lacruz, 2025). This involvement can take the form of outreach initiatives and collaborative projects with industry partners (Ortiz-Rojo et al., in press), further strengthening the sector's capacity for EI.

The findings of this study align with those of Jones et al. (2020), who reported a notable increase in the demand for metals such as copper and lithium since 2015. This context of expansion opens new avenues for the entry of companies into key productive sectors that are central to addressing sustainability challenges (Kennedy et al., 2024; IRENA, 2024, IPCC, 2023). Among these, the goal of advancing electromobility stands out, with the copper sector playing a pivotal role. It is precisely within these evolving dynamics that EI should be more investigated, particularly in terms of its contribution to sustainability and the role companies play in driving this transformation.

Beyond the copper sector, research efforts can also target other critical areas of mining production that support sustainability goals, such as lithium, cobalt, and nickel (Shannak et al., 2024). In the case of lithium, for example, Tarascon (2010) highlights its distinctive physical, chemical, and electrochemical properties, which underpin its broad applicability across various technological domains. One particularly significant use is in energy storage systems (Manthiram et al., 2013; Li et al., 2018), where lithium-ion batteries have become the leading technology for advancing renewable energy integration and electric mobility. Reflecting this growing strategic importance, the Chilean Copper Commission (Cochilco, 2024b) reported a 30% increase in the lithium exploration budget in 2024 compared to the previous year—making lithium the only metal among those commonly used in

primary batteries, such as nickel and cobalt, to record growth during this period. Thus, new business expansion opportunities may be also in other sectors such as lithium.

Limitations

In the decision tree technique applied in this study, the data covered a period of 11 years. Future studies could analyse global datasets spanning a longer timeframe to enhance the robustness of findings. Regarding the data used in the regression analysis, it corresponded to a single country. While this approach yields valuable insights—particularly given that the country is the world's largest copper producer—it limits the generalizability of the results. Future research could broaden the scope to include multiple countries.
Another limitation lies in the level of analysis, which, due to the aggregated nature of the data, prevents conclusions at the company level. Nevertheless, this is precisely the direction we recommend. Research on EI at both the individual level (e.g., top management teams) and the company level is essential. Accordingly, the following research agenda is proposed.

Research agenda

Considering all that has been discussed thus far, an agenda is proposed to guide future research and policy development. With the gaps identified in the literature in mind and the lack of empirical evidence from critical markets—such as the copper sector—regarding EI, several research questions emerge that warrant further investigation.

- First, it is essential to explore the drivers and barriers of EI in sectors that are pivotal to addressing sustainability and electromobility challenges. Previous studies have identified various factors influencing EI, including those by Lopez-Perez et al. (2024), Fernandez et al. (2021), Kiefer et al. (2018), Saez-Martinez et al. (2016), Cuerva et al. (2014), Trigueiro et al. (2013), Horbach et al. (2012), Chen (2008), and Horbach (2008), while barriers have been specifically discussed by Lopez-Perez et al. (2024) and Kiefer et al. (2018).
- Second, the role of externalities in shaping EI outcomes need to be examined, particularly the second order and third order externalities described by Chistov et al. (2021). These refer to the involuntary spillover of knowledge that can diminish firms' incentives to invest in EI, and the missed opportunities when firms fail to leverage such spillovers. Understanding how open innovation practices can manage these externalities is crucial for fostering EI development.
- Third, the influence of larger companies in incentivizing and supporting EI among SMEs deserves attention. This includes examining how larger firms contribute to shaping the intentions and behaviours of SMEs regarding EI, and under what conditions and when these intentions translate into actual adoption.
- Fourth, the role of the government trough public policies implementation aimed at fostering EI, must be addressed. This involves analysing how regulatory frameworks, financial incentives, and strategic programs can stimulate EI, reduce barriers, and promote collaboration across sectors and firm sizes.

Finally, these questions should be addressed through comparative empirical analysis across countries classified by the World Bank as low-income, lower-middle-income, upper-middle-income, and high-income. The focus should be on companies operating not just in copper markets, but rather including others that are central to the transition toward electromobility and sustainability, as lithium, cobalt, nickel etc. Thus, providing a comprehensive understanding of EI dynamics across diverse economic contexts.

This study demonstrates that shifts in the sector's dynamics have the potential to open new avenues for business development and expansion. As the market evolves, it may attract new entrants, and future EI intentions and behaviours can be fostered within a sector that is pivotal to sustainability and the growing demand for electromobility. Additionally, given the lack of empirical evidence in critical sectors such as copper and others like lithium, nickel and cobalt, further investigation into EI is essential. By applying two robust analytical techniques and interpreting the results, this study offers insights and an agenda that can inform future research endeavours and policymakers for the advancement of the EI field.

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