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Research Article

Foreign direct investment, renewable energy and governance in major copper- and lithium-mining countries

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Abstract. Funding the supply of critical materials for the transition to renewable energy (RE) is crucial to addressing climate change. For the world's leading economies in copper and lithium mining, this paper investigates the association among foreign direct investment (FDI), governance, carbon emissions (CO_2) and renewable energy consumption (REC). Using 2002–2023 panel data, a unit root test was applied to determine the stationarity of the variables and cointegration tests revealed cointegration in first differences. The variables were cointegrated at the 1% significance level, as indicated by the Kao Residual Cointegration Test. Next, the fully modified ordinary least squares (FMOLS) and dynamic ordinary least squares (DOLS) panel regression methods were employed. The FMOLS model findings indicated a long-term negative relationship between FDI and RE. Specifically, a 1% increase in FDI (as a percentage of GDP) reduces REC by 0.24% in the major copper- and lithium-producing economies. Governance, measured by control of corruption, has a positive effect on clean energy consumption, and CO_2 emissions are significantly negatively associated with REC. Using the DOLS model, we confirmed the robustness of these long-term panel relationships. Policymakers should strengthen the quality of governance, including combating corruption and encouraging FDI in RE. This strategy should also support sustainable mining practices and responsible consumption, aligning with Sustainable Development Goals (SDGs) 7 and 12, respectively.

Keywords: Foreign direct investment, renewable energy, governance, mining, CO_2 emissions

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1. Introduction

Renewable energy (RE) is both a mitigation and adaptation strategy for addressing climate change. By reducing greenhouse gas emissions, RE consumption (REC) helps mitigate climate change, while resilient RE infrastructure can adapt to the impacts of extreme weather (Rahman *et al.*, 2025). Several RE technologies are designed for climate resilience, such as solar energy systems that can withstand high temperatures and wind turbines engineered to endure extreme winds (Eitan, 2024). Furthermore, the technological diversification of clean energy strengthens adaptation efforts.

Global investments in sectors linked to the Sustainable Development Goals (SDGs) fell by 11% in 2024 compared with 2015 (United Nations Conference on Trade and Development (UNCTAD), 2025), even though foreign direct investment (FDI) may have recovered in 2025 amid favorable credit conditions. Copper is an essential mineral because of its multiple applications, including conventional uses in the manufacture of electric generators, motors and electronic products, as well as alternative uses in energy transition technologies, such as electromobility, photovoltaic panels and wind turbines (Maquet *et al.*, 2024). Lithium is used to manufacture batteries for energy storage.

FDI inflows to developing countries fell by 2% in 2024 compared with the previous year (Table 1), with FDI in 2023 also declining in the Global South. This trend hinders progress in international financing for projects linked to the Sustainable Development Goals. In Africa, FDI reached $94 billion in 2024, primarily driven by a major project in Egypt. In Latin America and the Caribbean, FDI fell by approximately 10%, even while the number and value of new projects increased in Brazil, Argentina and Colombia, indicating a possible future recovery. An FDI rebound is anticipated in critical mineral projects, such as copper and lithium, to support the energy transition and sustainable development.

Global FDI flows amounted to $1.4 trillion in 2024. However, excluding financial flows from European gateway economies, the UNCTAD, 2025) estimates that they declined by 8%. Globally, countries are seeking to mitigate the negative impacts of climate change. Using a multiregional integrated assessment model (IMACLIM-R) to examine various climate finance scenarios involving the interaction between public and private capital, Briera and Lefèvre (2024) demonstrated that international financing to address climate change can significantly improve RE adoption in developing economies and reduce the capital cost of RE investments. The progress and scale of the transition require that investment in clean energy not be limited to low-risk projects. To comply with the Paris Agreement, investing in higher-risk projects, especially in developing countries and emerging clean energy technologies, will be necessary (Montague *et al.*, 2024).

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Table 1
Foreign Direct Investment Trends, Developing Regions (billions USD) 2023-2024.

Region	2023	2024	Variation 2024/2023
Developing Economies	867	854	-2%
Africa	53	94	79%
Latin America and the Caribbean	193	173	-10%
Asia	621	588	-5%

Source: UNCTAD (2025). Compiled by authors.

Fang *et al.* (2024) argued that the negative effect of FDI has been effectively mitigated following the signing of the Paris Agreement. They suggest that improving governance capacity inhibits the negative impact of FDI on the RE structure. Additionally, Sarkodie *et al.* (2020) found that a 1% increase in the share of RE reduces greenhouse gas emissions by 35.32%. In contrast, a 1% increase in the coupling effect among income level, governance and REC intensifies climate change by 0.79%. Jaumotte et al. (2024) showed that more climate policies are associated with higher FDI flows into RE, especially in countries with solar energy potential and low reliance on fossil fuels.

Benfica and Marques (2024) evaluated the energy transition implementation in Latin America from 2015–2020. The negative correlation between gross fixed capital investment and the level of energy transition suggests that investing in green energy tends to be lower in countries with less effective transitions. Although Chile's regulatory framework favors competitiveness, its procedures are complex, especially for strategic investment projects (OECD, 2023). Foreign investors in Chile face greater challenges in public bidding processes than in other OECD countries, despite the promotion of FDI. Companies with negative environmental profiles face higher capital costs and loan interest rates; thus, implementing policy interventions to reduce these costs is essential. Achieving this requires innovation and the strengthening of financial markets through an integrated approach that links climate finance to economic and social development (Meneses Cerón *et al.*, 2024). In response to perceived economic barriers to investing in RE, countries in both the global North and South have introduced various promotion mechanisms and subsidies at different points in time (Christophers, 2021).

The rationale behind this study is that the decarbonization of the world's economies requires financing the transition to renewable energies. One important way to achieve this is to encourage FDI to develop clean technologies in countries that are leaders in critical mining resources, such as copper and lithium. The global challenge is to ensure that investment in RE exceeds that in fossil fuels to mitigate climate change by attracting FDI, a crucial step toward achieving the SDGs. These goals include Goal 7 on affordable and clean energy, SDG 9 on industry, innovation and infrastructure, SDG 12 on responsible consumption and production and SDG 13 on climate action by 2030. This study aimed to analyze the relationship between FDI and RE in leading copper- and lithium-mining countries and to explain how FDI, governance and CO_2 emissions influence REC in these key nations.

This study examines the impact of FDI financing on RE use in major copper- and lithium-producing countries, in the context of climate change. Recognizing the necessity of FDI in the transition from fossil fuels to clean and sustainable energy, the findings of this study are relevant to countries that produce other critical materials and, more generally, to countries committed to achieving low-carbon or carbon-neutral economies. The research further examines whether FDI and governance promote or hinder REC in major copper- and lithium-mining economies. In the context of RE's role in mitigating climate change, this study aims to address a gap by analyzing the relationship between FDI and REC in the world's leading copper- and lithium-mining economies.

2. Literature review

FDI refers to investments made by foreign entities in domestic companies or infrastructure in another country. It is recognized as a key driver of economic development (Nor and Mohamud, 2024). FDI can provide capital and technology to develop Somalia's RE sector. FDI has led to widespread competition among industrialized and developing countries to attract the largest share of this inflow (Raihan *et al.*, 2025). The rise and fall in mineral prices generate volatility in tax revenues in Latin America and the Caribbean and also impact FDI levels (León *et al.*, 2020). Governance refers to the interaction between and decision-making of various public and private actors involved in managing access to and exploitation of mineral resources.

Sustainable energy development serves as a transition paradigm for sustainable development. Akpan and Olanrewaju (2023) explored energy financing and the need for 100% RE, which forms part of the decarbonization strategy, and also analyzed energy storage options, with hydrogen emerging as the most promising. Tsepi *et al.* (2024) recommended the urgency of a sustained focus on the penetration of RE sources to reduce CO_2 emissions. Eighty-two percent of mining areas are dedicated to materials critical for RE production (Sonter *et al.*, 2020).

Following COP28 on financing clean energy investments, Khan *et al.* (2024) revealed, using data from 1990–2019, that public R and D budgets for energy, increased revenues, improved political risk indices and the promotion of clean energy are relevant for achieving sustainable development in G7 countries, and that the depletion of natural resources has a negative influence on sustainability. Castrejon-Campos *et al.* (2022) used a two-factor learning curve model to estimate implementation learning rates of 31.4% for onshore wind energy and 27.6% for solar photovoltaic energy in the United States. Using a logistic curve approach, they predicted that an additional $1.322 billion and $819 million would be spent by 2050 on R and D for wind and solar energy, respectively. RE reduces CO_2 emissions in OECD countries (Kahouli et al., 2025). According to Dou *et al.* (2023), countries are launching their roadmaps to achieve carbon neutrality and are making significant investments in clean energy and transportation to enhance their national competitiveness. This transition requires critical minerals. Martínez-Alonso *et al.* (2023) demonstrated for the first time that annual NOx emissions from individual copper and cobalt mines, as measured by TROPOMI satellite data, are strongly correlated with annual production at these sites. Utilizing satellite-derived emission data alongside mine production reports can help improve the traceability of minerals from conflict zones.

Dossou *et al.* (2023) empirically evaluated the relationship between FDI and RE deployment in 37 sub-Saharan African economies from 1996–2020. They found that RE development requires FDI, which is attracted by good institutions. Boafo *et al.* (2024) highlighted the socioecological impacts of critical mineral extraction in Africa. According to Famanta *et al.* (2024), there is debate regarding the pollution halo (FDI improves environmental quality) and pollution refuge (FDI negatively affects environmental quality) hypotheses. Green FDI refers to foreign investors injecting clean technologies, practices, projects and capital into a host country to support development and address climate change, pollution and the depletion of exhaustible resources.

The minerals that attract the greatest FDI are cobalt, lithium and rare earth elements (Bonnet, 2025). Chaudary (2025) noted that researchers have attributed the socioecological cost of lithium to green extractivism. Kayani *et al.* (2024) examined the relationship between carbon emissions and FDI in the BRICS countries—Brazil, Russia, India, China and South Africa—and recommended applying strict regulatory measures and proactive mining waste recycling measures to mitigate the environmental footprint of mining operations. To mitigate climate change, Tan and Uprasen (2022) proposed intensifying local environmental regulation to guide FDI inflows from multinational companies toward REC. Kilicarslan (2019) found that FDI negatively affected RE production in the BRICS countries and Turkey, using an autoregressive distributed lag (ARDL) panel analysis from 2007–2015, which indicated that FDI is not directed toward the RE sector. Osuma and Bonga-Bonga (2025) observed a negative effect of FDI on REC, suggesting that foreign investment may not be effectively driving the expansion of RE, either because FDI is directed toward the traditional energy sector or because recipient countries lack adequate regulatory frameworks for sustainable energy investments. Tran *et al.* (2025) used the generalized method of moments to show that FDI negatively impacts REC across a panel of 110 countries from 1990–2020.

Kang *et al.* (2021) used fully modified ordinary least squares (FMOLS) and dynamic ordinary least squares (DOLS) models, covering annual data from 1990–2019. The FMOLS approach revealed a significant and negative link between FDI and RE in South Asian nations (Sri Lanka, Pakistan, India and Bangladesh). The DOLS model produced the same results, confirming its robustness. Elheddad *et al.* (2022) found that FDI inflows increase CO_2 emissions in the Bangladeshi economy, and multinationals promote the use of non-RE sources, increasing pollution. Furthermore, incoming FDI discourages the consumption of renewable energies, and its negative impacts on REs outweigh its positive effects on CO_2 emissions. In a survey of senior executives conducted in January 2025, the United States and Canada led Kearney's FDI Confidence Index (2025), with investors highlighting US technological innovation and the high quality of Canadian infrastructure. The United Kingdom and Germany lead in Europe, ranking third and fifth, respectively, and in the Asia-Pacific region, Japan ranks fourth in the Index. Of the leading copper-lithium countries, only two are among the 25 most reliable countries for FDI: China, which fell from third to sixth place compared to 2024, and Australia, which remains in tenth place.

Namahoro *et al.* (2025) examined the global production of critical materials—nickel, manganese, cobalt, platinum and bauxite (primary aluminum ore)—driven by FDI between 2016–2021. The study found that FDI controlled 16 manganese mines, 26 nickel mines, 22 cobalt mines, 24 platinum mines and 13 bauxite mines in countries vulnerable to clean energy. Raihan *et al.* (2025) documented that the FMOLS methodologies developed by Hansen and Phillips, the DOLS method from Stock and Watson and the CCR approach by Park effectively address endogeneity, serial correlation, omitted variable bias and measurement errors. Before applying the cointegration test, the cointegration condition between the I(1) variables must be satisfied.

3. Methodology

The study's research approach was quantitative, applied, nonexperimental and longitudinal. The research on FDI, RE and governance covered the period from 2002–2023. Spatially, it encompassed the behavior of the study variables in the leading countries for copper exploitation (Chile, Democratic Republic of the Congo, Peru and China) and for lithium (Australia, Chile, China and Argentina). The universe comprises the World Bank records of FDI and REC by country. The sample is nonprobabilistic and consists of yearly data from 2002–2023 of FDI and REC in the selected countries. The unit of analysis was the world's leading copper- and lithium-mining countries.

3.1 Sources of information

The documentation sources included journals and scientific articles on foreign investment and energy transition, as well as countries that produce critical minerals. Data from the World Bank and the UNCTAD were collected to analyze the leading countries in copper and lithium production. The econometric models were estimated using SPSS and Eviews software.

3.2 Data collection techniques

Secondary information was gathered from the World Bank and UNCTAD databases and statistical yearbooks. These data indicate annual trends in FDI and REC (2002–2023). Additionally, the World Governance Indicators for government effectiveness and control of corruption were used, both measured as percentile ranks. Ethically, the research data are based on publicly available information. The FDI variable represents net capital inflows as a percentage of GDP, as in Korani (2025). Pearson's correlation technique and panel data analysis were subsequently applied to the variables under investigation.

3.3 Procedure

First, data were collected on FDI and REC in the primary countries that have copper and lithium mines. The second point examined the trend in FDI across major copper- and lithium-mining countries. The third point highlighted the connection between FDI and RE in these nations. Furthermore, the relationships among RE, CO_2 emissions and governance in these key copper- and lithium-producing countries were analysed using Pearson's correlation.

Next, a panel data analysis for 2002–2023 was conducted of six leading copper and lithium countries: Chile, the DRC, Peru, China, Australia and Argentina. The study's dependent variable is REC (Kang *et al.*, 2021; Nor and Mohamud, 2024; Osuma and Bonga-Bonga, 2025). The explanatory variables include net FDI, government effectiveness, control of corruption and CO_2 emissions. The latter variable was also considered an explanatory factor by Kang *et al.* (2021) and Korani (2025). We selected the FMOLS method for the panel analysis. Before this, unit root tests were conducted, and first differences of the original (level) series were taken to assess stationarity and cointegration (Raihan *et al.*, 2025). For the robustness analysis, we applied the DOLS model, a parametric method for estimating long-term relationships between variables. FMOLS and DOLS address the issues of

endogeneity—when an explanatory variable correlates with the error term—and serial correlation (also known as autocorrelation) (Kirikkaleli and Adebayo, 2021). FMOLS is a nonparametric regression method that also corrects heteroscedasticity.

Model specification

$$REC = f(FDI, GOV, CO_2), \quad (1)$$

where REC stands for REC, FDI refers to net FDI, GOV represents governance, and CO_2 denotes carbon dioxide emissions.

Econometric model

$$REC = \beta o + \beta 1\ FDI + \beta 2\ Geff + \beta 3 CorrupC + \beta 4 CO_2\ emiss + \varepsilon. \quad (2)$$

The dependent variable is REC, expressed as a percentage of total final energy consumption. The regressors are FDI, and the variable CO_2 emissions reflects fossil fuel consumption, such as coal, oil and natural gas (Korani, 2025). Government effectiveness (Geff) and corruption control (CorrupC) are two indicators of governance (GOV), and ε is the residual. In Eq. (2), β_0 is the intercept, and β_1 through β_4 are the coefficients of the independent variables.

4. Results and discussion

4.1 Descriptive analysis and tests of stationarity and cointegration

Among the leading copper-producing countries, Fig. 1a illustrates the evolution of copper production (in millions of fine metric tons) for the four countries from 2002–2024, with Chile leading. The Democratic Republic of Congo (DRC) became the world's second-largest copper-producing country in 2023–2024, pushing Peru into third place in the global copper rankings, from exploiting high-grade deposits, such as Kamoa-Kakula (Basurto, 2025), with FDI from China and lower operating costs than in South America. China's strategy is to invest in countries rich in natural resources yet politically unstable, such as the DRC (Altiparmak *et al.*, 2025); the Netherlands also exports FDI in copper mining to the DRC. Fig. 1b shows Australia at the top of production (TMF) among the world's four leading lithium-mining countries, followed by Chile, an economy rich in critical materials. Lithium production costs in Chile average $4,000 per ton of lithium carbonate equivalent (LCE), compared with $10,000–15,000 for spodumene mining in Australia (Mura *et al.*, 2025).

Fig. 2 illustrates FDI in terms of net capital inflows (income minus capital outflows) for the leading copper and lithium countries from 2002–2023, highlighting 2012 as the year with the highest net FDI, coinciding with high international prices for mining resources; in contrast, a notable drop in FDI due to the COVID-19 health crisis occurred in 2020. Australia experienced a net capital outflow of −3.6% of GDP in 2005, meaning FDI outflows exceeded capital inflows. Although FDI in lithium was not significant in Australia in 2005, Tianqi (China) and Albemarle (US) began investing in lithium extraction and refining in 2009. There was also a net capital outflow of −1.3% of GDP in the DRC in 2009, specifically in the copper sector, due to the 2008–2009 global economic crisis. Namahoro *et al.* (2025) highlighted the use of FDI for material extraction rather than clean energy development.

Fig. 3 shows REC as a proportion of total energy consumption in the six leading copper- and lithium-producing countries. Notably, the DRC relies heavily on RE, which accounts for approximately 96% of its total energy consumption. The DRC's electricity is generated primarily by hydroelectric power plants on the Congo River, with the Grand Inga hydroelectric project playing a vital role in the country's RE development. The DRC faces political, geostrategic and financial challenges (Gnassou, 2019). Argentina and Australia

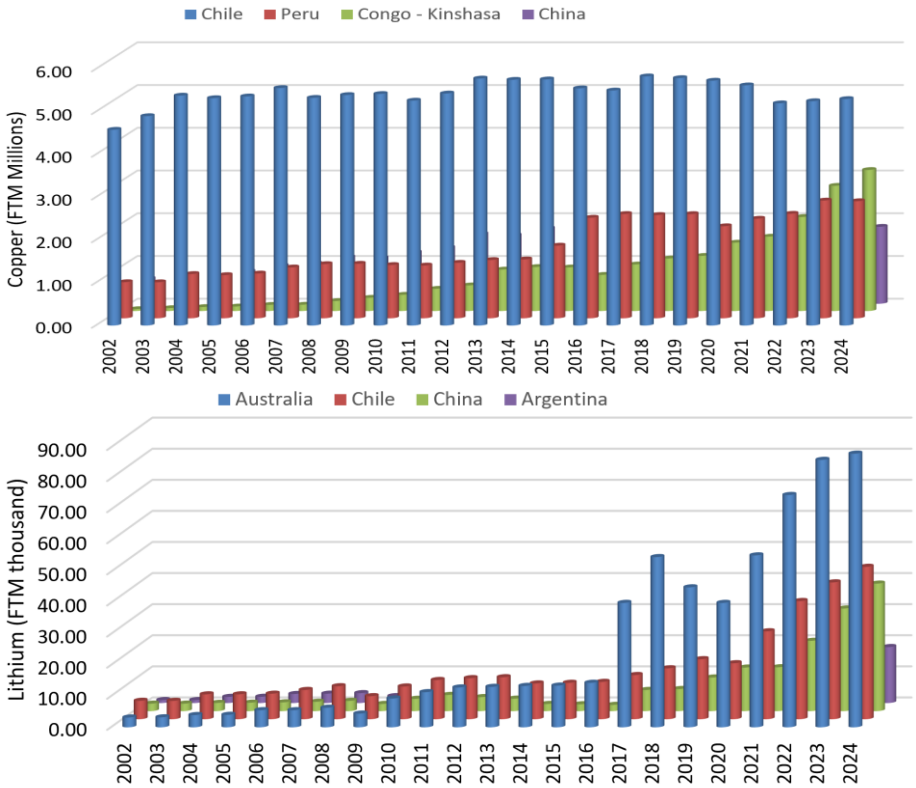

Fig. 1 World's leading mining countries, 2002–2024: a) Copper (FTM Millions), b) Lithium (FTM thousands)
Source: US Geological Survey. Mineral commodity summaries (2004-2025). Authors' compilation

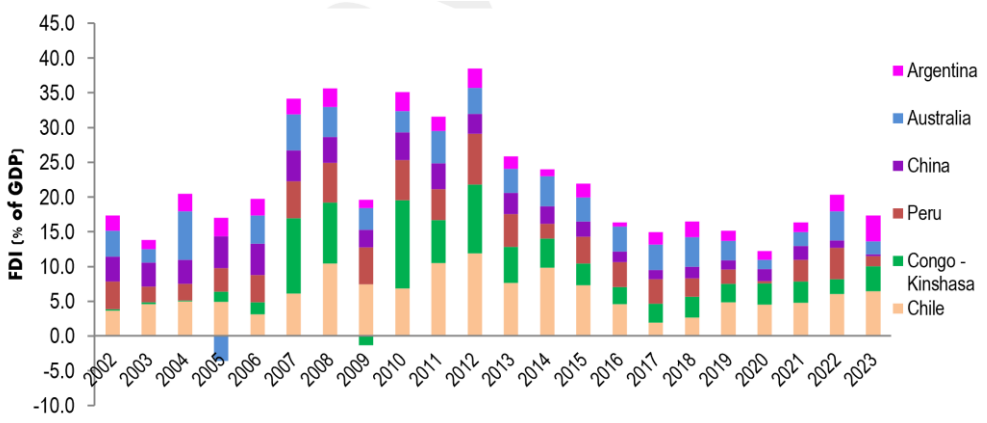

Fig. 2. Foreign direct investment from top copper-lithium countries, net capital inflows (% of GDP)
Source: World Bank (Authors' compilation)

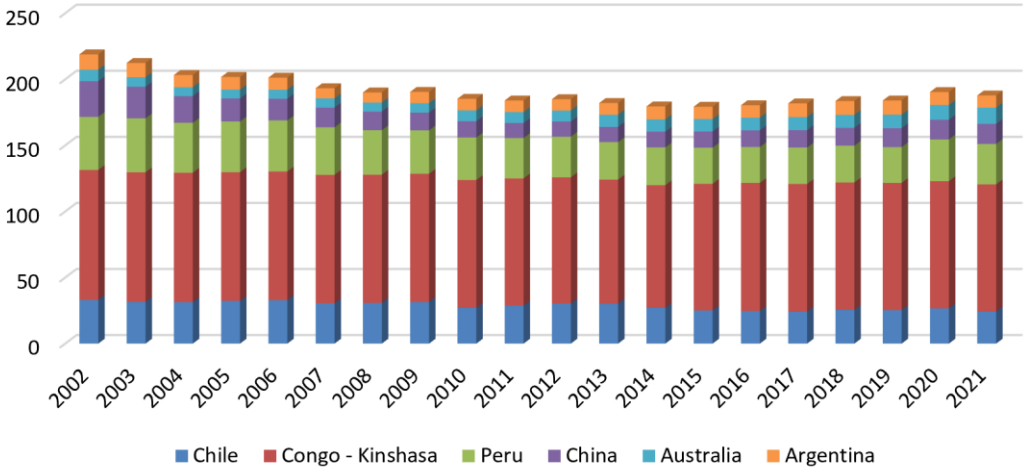

Fig. 3. Renewable energy consumption (% of total energy consumption), top countries in copper-lithium

Table 2
Descriptive statistics

	Reconsumption	FDI	Geffectiveness	Contcorruption	Tco2emissions
Mean	31.79000	3.675831	54.92530	51.77863	1.53E+09
Median	24.15000	3.135286	54.50932	44.89280	1.08E+08
Maximum	98.30000	12.71601	96.11651	96.55173	1.14E+10
Minimum	6.700000	-3.606928	1.081081	0.975610	2720283.
Std. Dev.	30.58286	2.570459	29.68369	31.34700	3.25E+09
Observations	120	120	120	120	120

have the lowest REC, at around 9% of total energy consumption. Lithium production costs in Chile average $4,000 per ton of LCE, compared with $10,000–15,000 per ton for spodumene mining in Australia (Mura *et al.*, 2025).

As shown in Table 2, the average share of RE in total energy consumption in countries with primary copper and lithium mining is 31.79%. The minimum is 6.7% in Australia, whereas the maximum is 98.3% in the DRC, as illustrated in Figure 5. Net FDI averaged 3.68% of GDP. Governance indicators, such as government effectiveness and corruption control, show averages at the 54.93rd and 51.78th percentiles, respectively. On average, these leading copper- and lithium-producing countries generate 1.53 million tons of CO_2 emissions.

As shown in Table 3, there are no significant country-level relationships between REC and FDI in the primary copper- and lithium-producing nations. However, Chile shows a strong correlation between REC and governance indicators, including government effectiveness and control of corruption. Peru also exhibits a positive correlation between REC and corruption control. There is a strong negative relationship between REC and carbon dioxide emissions among the leading copper- and lithium-mining countries, except for Australia. But the level series are nonstationary, and there are problems of autocorrelation or serial correlation. Using panel data from six countries that lead the world in copper and lithium mining, we evaluated whether the variables were stationary and cointegrated.

Table 3
Correlations: Renewable energy consumption, FDI, governance, and CO2e, top countries in copper-lithium 2002-2023

Pearson's correlation: r		FDIn	Geffectiviness	ContCorruption	CO2emissions
REC_Chile	r	0.163	0.757**	0.727**	-0.844**
	p-value	0.493	0.000	0.000	0.000
REC_Congo	r	-0.262	-0.437	-0.504*	-0.493*
	p-value	0.265	0.054	0.024	0.027
REC_Peru	r	0.024	-0.675**	0.620**	-0.952**
	p-value	0.919	0.001	0.004	0.000
REC_China	r	0.328	-0.463*	-0.240	-0.797**
	p-value	0.158	0.040	0.307	0.000
REC_Australia	r	-0.097	-0.649**	-0.503*	0.263
	p-value	0.683	0.002	0.024	0.263
REC_Argentina	r	-0.304	0.034	0.291	-0.565**
	p-value	0.192	0.887	0.213	0.009

**. The correlation is significant at the 0.01 level (two-tailed). n=20
*. The correlation is significant at the 0.05 level (two-tailed).

Table 4
Panel unit root tests

Variable	LLC	Prob.	IPS	Prob.	ADF	Prob.	PP	Prob.	order
REC	-6.66233	0.0000	-6.41552	0.0000	59.3174	0.0000	61.6762	0.0000	I(1)
FDI	-3.09035	0.0010	-3.16654	0.0008	34.3876	0.0006	46.4116	0.0000	I(0)
Gov_effectiv	-8.59878	0.0000	-8.17779	0.0000	76.9220	0.0000	103.195	0.0000	I(1)
Contr_corrupt	-10.2032	0.0000	-9.31262	0.0000	86.5809	0.0000	92.1272	0.0000	I(1)
CO2	-3.84807	0.0001	-1.95069	0.0255	21.9230	0.0384	22.1605	0.0358	I(0)

Table 5
Panel cointegration test

Series: D(REC) D(FDI) D(Gov_effectiv.) D(Cont_corrupt.) D(CO2)				
Pedroni Residual Cointegration Test				
	Stat.	Prob.	W_Stat.	Prob.
Panel v-Statistic	-1.097772	0.8638	-1.445808	0.9259
Panel rho-Statistic	-0.414931	0.3391	0.213600	0.5846
Panel PP-Statistic	-4.976429	0.0000***	-3.301206	0.0005***
Panel ADF-Statistic	-4.510625	0.0000***	-2.988503	0.0014***
Group rho-Statistic	0.632480	0.7365		
Group PP-Statistic	-4.531714	0.0000***		
Group ADF-Statistic	-2.139023	0.0162**		
Kao Residual Cointegration Test				
	t-Statistic	Prob.		
ADF	-2.814522	0.0024***		

***p < 0.01, **p < 0.05, *p < 0.1

Table 4 shows the results of the unit root tests using the following models: Levin, Lin and Chu (LLC); Im, Pesaran and Shin; Augmented Dickey–Fuller (ADF); and Phillips–Perron (PP). FDI and CO_2 emissions are stationary at zero order. REC and governance indicators are nonstationary at the level. Nevertheless, all panel variables are stationary in first differences; that is, they are integrated of order one (I(1)).

The panel series in first differences passed most of Pedroni's cointegration tests (Table 5), and the null hypothesis of no cointegration was rejected. According to Kao's residual cointegration test, the variables are co-cointegrated at a 1% significance level. The dependent variable, REC, exhibits long-term relationships with the explanatory variables.

4.2 The relationship between FDI, governance and RE

The FMOLS method was applied to the stationary panel data series in first differences and to the cointegrated series to correct for endogeneity bias and serial correlation and to identify long-term relationships between the variables. Table 6 shows that FDI negatively affects REC in the leading copper- and lithium-mining economies. The FMOLS panel regression results show that a 1% increase in FDI (as a percentage of GDP) reduces REC by 0.24% in the leading copper- and lithium-producing economies. Corruption control directly influences clean energy consumption, and there is a significant negative relationship between CO_2 emissions and RE at the 1% level. In Fig. 4a, the residuals are normally distributed around their mean. For robustness, the DOLS panel method was used (Table 6). FDI, carbon dioxide emissions and government effectiveness have an inverse effect on REC. Meanwhile, corruption control positively affects clean energy consumption in countries that lead in copper and lithium production. According to the Jarque-Bera statistic, the residuals are normally distributed (Fig. 4b).

This study found that FDI negatively impacts REC in the world's leading copper- and lithium-producing countries (Table 6). Comparatively, Fang *et al.* (2024) found that FDI has a significant negative impact on the structure of REC in both high- and lower-middle-income countries. The negative impact of FDI is greater in lower-middle-income countries due to weaker environmental regulation and greater reliance on fossil fuels.

Table 6
Fully Modified Ordinary Least Squares (FMOLS) and Dynamic Ordinary Least Squares (DOLS) panel estimation
Dependent Variable (REC)

	FMOLS				DOLS			
Variable	Coefficient	Std. Error	t-Statistic	Prob.	Coefficient	Std. Error	t-Statistic	Prob.
FDI	-0.2441	0.12648	-1.93035	0.0563	-0.2802	0.16161	-1.73407	0.0891
Gov_effectiv	-0.1147	0.06462	-1.77438	0.0789	-0.2428	0.08506	-2.85418	0.0063
Contr_corrupt	0.3873	0.05964	6.49389	0.0000	0.50194	0.08014	6.2634	0.0000
CO2	-1.95E-09	4.17E-10	-4.68312	0.0000	-1.18E-09	5.20E-10	-2.26871	0.0276
R-squared	0.99555				0.99859			
Adjusted R-squared	0.99517				0.99698			

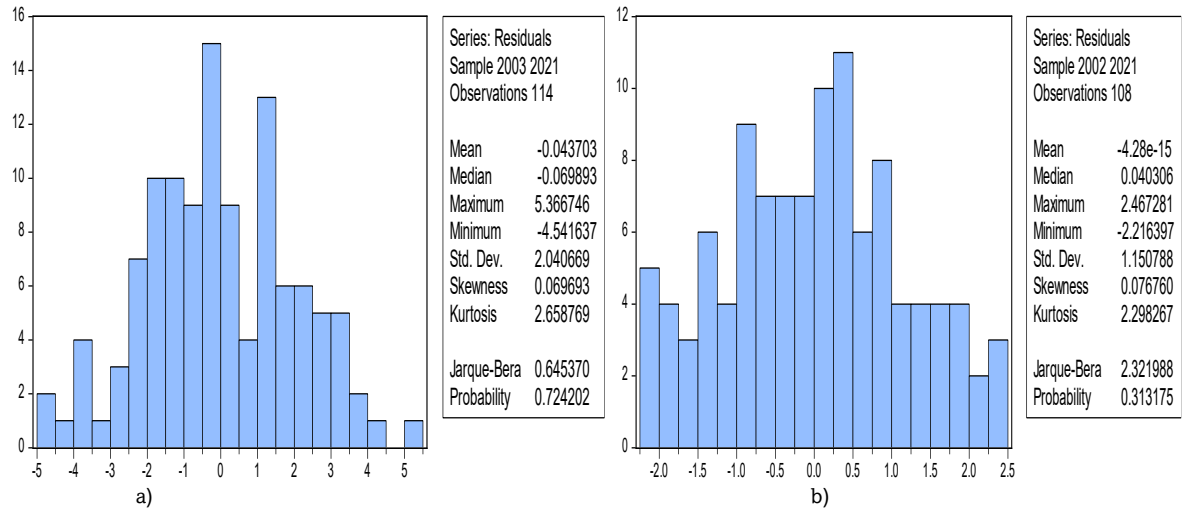

Fig. 4. Normality tests: a) FMOLS, b) DOLS

Similarly, using an ARDL panel model (2007–2015) in the BRICS countries and Turkey, Kiliçarslan (2019) found that FDI inflows harmed RE production.

The DOLS panel method used to assess robustness indicates that a 1% increase in FDI (as a share of GDP) is associated with a 0.28% decrease in the share of RE in total final energy consumption (Table 6). Osuma and Bonga-Bonga (2025) also found a negative effect of FDI on REC. To develop clean energy, they recommend that the government restructure investment policies to attract foreign capital to sustainable energy projects and discourage FDI in fossil fuels. Similarly, using the generalized method of moments/dynamic panel data (GMM/DPD) approach, Korani (2025) found that in European economies from 2010–2022, FDI had a significant negative impact on RE generation. The findings imply that policymakers should implement incentive programs to redirect FDI from non-RE sources to RE projects. A feed-in tariff (FIT) is a fixed price per kWh, whereas a feed-in premium (FIP) is a fixed or variable premium above the market price that transfers some of the risk to the producer.

Countries are transitioning from FITs to FIPs as the supply of renewable technologies, such as solar and wind, grows. A FIT offers a fixed price to RE producers. IP is an additional subsidy on top of the market price received by the electricity producer (Nguyen and Ponomarenko, 2025). Davi-Arderius *et al.* (2023) argued that RE auction designs should prioritize addressing indirect costs rather than solely focusing on minimizing/ subsidies in geographically neutral auctions. In geographically diverse auctions, a broader distribution of RE projects results in higher subsidies but lower network costs, thereby reducing system costs. Namahoro *et al.* (2025) measured the vulnerability of countries rich in critical materials to clean energy risks. They mitigated this vulnerability by strategically redirecting FDI related to mining projects toward energy development. In our study of the panel of leading copper-lithium countries, policies should be reoriented toward promoting FDI in infrastructure and sustainable energy transition projects. The focus of FDI announcements in Latin America and the Caribbean is copper mining, mainly in Chile and Peru (ECLAC, 2025). Studies of individual countries, such as those conducted by Dey and Islam (2023) in Bangladesh, have found a negative impact of FDI on energy consumption in both the short and long term using the ARDL approach to analyse data from 1971–2014. In contrast, Nor andand Mohamud (2024) discovered a positive relationship between FDI and long-term REC in Somalia.

On the other hand, we found a significant negative relationship between CO_2 emissions and RE, which supports the idea that reducing CO_2 emissions leads to greater use of clean energy. Coincidentally, Ali *et al.* (2025) found that CO_2 emissions hinder REC across 36 Asian countries, suggesting that emissions drive the political transition to RE. In contrast, research by Kang *et al.* (2021) revealed a positive effect of CO_2

on REC in South Asian economies. Our study is consistent with the shift to RE sources (Kiliçarslan, 2019), which are necessary to meet greenhouse gas emission reduction targets. Adjei-Mantey andand Adams (2023) also found a negative relationship between REC and both territorial and consumption-based CO_2 emissions. Xu *et al.* (2023) showed an inverse correlation between RE and CO_2 emissions in E-7 countries. One indicator of governance and government quality is the ability to control corruption. In our panel study of leading copper- and lithium-producing countries, we found that government efforts to control corruption have a direct impact on clean energy consumption at the 1% significance level (Table 6). By comparison, Dossou *et al.* (2023) identified a positive correlation between government quality and RE.

5. Conclusion

From 2002–2024, Chile led the world in copper production. The DRC ranked second in global copper mining from 2023–2024. Australia is the world's leading lithium producer, followed by Chile. Net FDI for leading copper and lithium countries has evolved in line with the global context. The year 2012 saw the highest net FDI, coinciding with high international prices for mining resources.

In contrast, 2020 saw a decline in FDI due to the COVID-19 pandemic. Australia experienced a net capital outflow of −3.6% (of GDP) in 2005, and FDI in lithium was not significant in Australia in 2005. There was also a net capital outflow of −1.3% of GDP in the DRC in 2009, specifically in copper, due to the 2008–2009 global economic crisis. On average, the top copper- and lithium-mining countries consume 31.79% of their total energy from renewable sources, with the DRC consuming up to 98.3%. There is no significant country-level Pearson correlation between REC and FDI among the top copper- and lithium-mining countries. However, Chile and Peru show a close correlation between RE and the governance indicator, control of corruption. A strong negative relationship was found between REC and carbon dioxide emissions, except in Australia.

In panel unit root tests, all panel variables are stationary and integrated of order one. The panel series in the first differences are cointegrated according to the Pedroni and Kao tests. To estimate the influence of FDI, governance and carbon emissions on REC, the panel regression method FMOLS was applied, which corrects for endogeneity and serial correlation biases and estimates long-term relationships between variables. The results revealed that FDI and CO_2 emissions negatively impact REC in major copper- and lithium-producing economies. Governance, measured by the control of corruption, directly influences clean energy consumption. To ensure robustness, a DOLS panel model was applied. DOLS confirmed that FDI and CO_2 emissions negatively affect REC, whereas the control of corruption positively affects renewable energy. The research findings showed that FDI does not favor REC, whereas controlling corruption improves it in major economies with copper- and lithium-mining operations. It is recommended that policymakers in countries with critical mineral resources strengthen governance quality, such as corruption control and government effectiveness, to attract FDI in renewable and affordable energy and to encourage responsible mining production and consumption, which correspond to SDG 7 and 12, respectively.

The study's limitation was a lack of monetary data and/or the percentage of GDP for specific time series of FDI in copper and lithium mining by country. Future research could compare historical FDI in the extraction of essential mining resources with FDI projections in critical mining for the energy transition by 2050.

Author contributions

Edelina Coayla: Writing – review & editing, Writing –original draft, Investigation, Formal analysis, Methodology Conceptualization, Supervision. Ysabel Bedón: Writing –original draft, Data curation. Robert Chávez: Resources, Visualization.

Declaration of competing interest

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