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Copper and Lithium Industrialization by Major Producing Countries for Mining Sustainability

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ABSTRACT

This research objective is to analyze the prospects of copper and lithium industrialization for the mining sustainability of the world's major producing countries. An expo-facto design was used based on a documentary analysis, considering the world ranking of the top copper-producing countries, where Chile, Peru, China, and the Democratic Republic of Congo stand out, and regarding lithium production, Australia, Chile, China, and Argentina stand out. On a global level, the presence of South American countries with mining resources in exploration and extraction is relevant; in contrast, China, a mining country, not only extracts natural resources but has advanced in the value chain with competitive advantages and consequent economic development; for its part, the DR of Congo (Africa), has ascended in the copper extraction ranking. The motors and electrical systems of electromobility vehicles are manufactured with copper and the batteries with lithium, which contributes to the mitigation of greenhouse gas emissions and thereby to environmental sustainability. Furthermore, the correlation between copper and lithium demand for electric vehicles in a 2050 zero-emission scenario is strong. There are social conflicts, mainly over the use of water; therefore, it is necessary to implement mining policies that lead to sustainable development.

Keywords: Industrialization, Copper, Lithium, Mining Resources, Development, Sustainability
JEL Classifications: L72, Q32, Q42, Q56

1. INTRODUCTION

The evolution of humanity throughout history has been linked to the knowledge and use of minerals, thus the stone, copper, and iron ages (Pastor et al., 2023). In South America, there are important reserves of minerals such as copper and lithium, located in Argentina, Bolivia, Chile, and Peru (Cortés and Yeluri, 2021). Globally, there are also reserves in China for both minerals and in the case of lithium, the leading producer to date is Australia.

Lithium metal is usually extracted from hard rock deposits (mostly in Australia and China) or brine (predominantly in Chile and Argentina), in the latter, mineral-rich brine from subway reserves in salt flats is first pumped into subway ponds and allowed to evaporate under the strong sun and dry winds of the deserts (Ciftci and Lemaire, 2023). In Australia, the world's leading producer of lithium ores for batteries, there is no evidence of lithium conflicts, nor in China. In contrast, in Chile and Argentina, there are many cases of conflict over lithium and non-transitional resources (Ciftci and Lemaire, 2023).

Currently, energy demand is marked by the transition from fossil fuels to clean energies in order to mitigate global warming, the energy sector being one of the largest emitters of GHGs into the atmosphere. Lithium is a key resource for the future economy around green energies (Carrasco et al., 2023). The low-carbon energy transition cannot be fair and "green" without the participation of indigenous residents in the countries of origin, as well as end users of EVENSS (electric vehicles, lithium-ion battery-powered vehicles, and energy storage systems) in China and the Global North, in the full distribution of its costs and benefits (Ciftci and Lemaire, 2023).

It turns out to be necessary to opt for the use of electric vehicles with lithium batteries, for the manufacture of the same, various metals are required, but especially copper for the wiring of vehicles and power plants, while lithium is for energy storage, i.e. for the batteries (Pastor et al., 2023).

For Leiva González and Onederra (2022), defining mining sustainability is a complex task due to the multidimensional approach to sustainability. Mining companies need to implement diverse and sustainable strategies to reduce the environmental impact in the different stages of the mining life cycle; in the socioeconomic aspect, there are diverse stakeholders that mining processes can affect negatively or positively and it is the responsibility of the mining industry to meet the diverse needs of these groups.

In this context, the objectives of this research are to analyze the prospects of copper and lithium industrialization for mining sustainability, considering the impact on the economic, social, and environmental development of the main producing countries.

2. METHODS

An expo-facto design was used based on a documentary analysis, following the world ranking of the main copper and lithium producing countries; the data were collected from the U.S. Geological Compendium (2024) "Mineral commodity summaries 2024", the Peru Mining Yearbook 2022, ECLAC, among others. The sample of this study is composed of four countries: Chile, Peru, China, and the Republic of Congo, which produced the highest level of copper production measured in fine metric tons in 2023; in terms of lithium production, the four countries that lead the ranking, which are Australia, Chile, China, and Argentina.

The procedure consisted of examining the impact of copper and lithium industrialization on economic and environmental sustainability and social development. Projections of copper and lithium demand for the manufacture of electric vehicles in a zero-emissions scenario to 2050, obtained from the International Energy Agency, were also used to calculate the degree of association between copper and lithium demand.

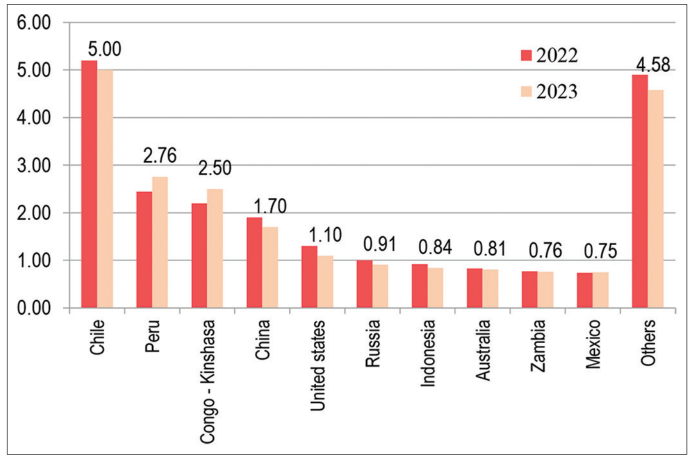
3. RESULTS AND DISCUSSION

World copper production in 2023 was around 22 million fine metric tons and the four main producing countries produced 12 million tons (Figure 1).

Chile is the world's largest copper producer and Peru ranks second by 2023 (Figure 2), however, the Republic of Congo is projected to follow Chile in the coming years.

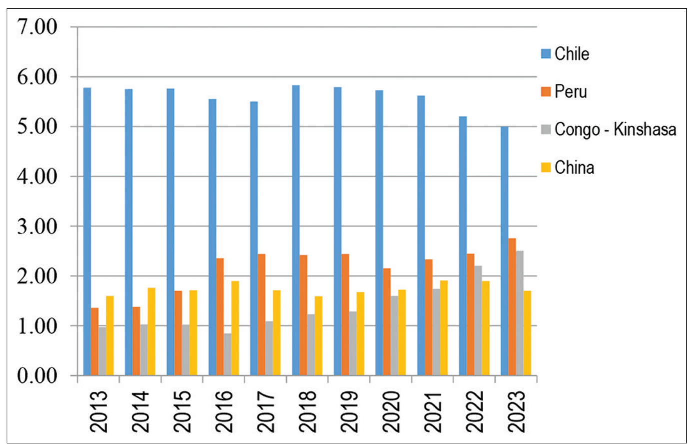
As for lithium, the leading lithium-producing country is Australia, followed by Chile and China (Figure 3). Australia mined 86 thousand fine metric tons in 2023.

Figure 1: World copper production by country (FTM Million)



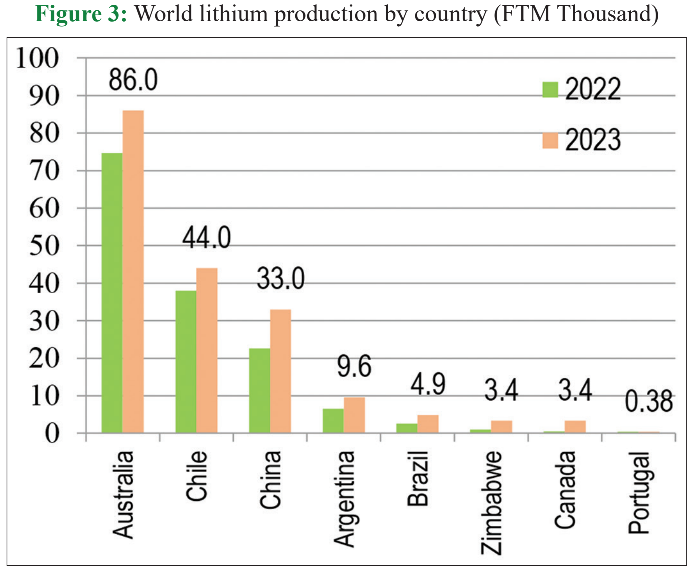
Source: Anuario Minero Perú 2022; Mineral Commodity Summaries 2024

Figure 2: Main copper-producing countries in the world (FTM Million) 2013-2023



Source: Anuario Minero Perú 2022; Mineral commodity summaries 2024

Figure 3: World lithium production by country (FTM Thousand)



Source: Mineral commodity summaries 2024

3.1. Impact of Copper and Lithium Industrialization on Economic Sustainability

Based on data on production, export, prices, mineral rents, exploration expenditures, and public revenues, Ericsson and Löf (2019) analyze the contribution of mining to economic development in the years 1996-2016, they found that the contribution of mining to GDP and exports peaked in 2011. Furthermore, they preliminarily conclude that mining countries perform better than oil-producing and non-mining countries in Africa; geographically, Africa as a whole, and in particular West Africa, is a good example of the economic development of mineral-producing countries.

Namahoro et al. (2022) examine the impact of revenues generated from copper production on economic growth in countries producing a higher level of copper over the period 2002-2016. They classify countries due to regional variations in copper production copper price volatility in the international market, and patterns and changes in economic growth among regions. They showed that the effect of copper production on economic growth is positive and significant globally and in the regions of North America, South and Central America, Europe and Central Asia, and Asia-Pacific, while it is insignificant in Africa and the Middle East.

González et al. (2023) compare the financial profitability of nationalized Chilean mines from 1967 to 2022 with a hypothetical counterfactual scenario had these mines remained privately owned; ex-post NPV evaluation at a 10% discount rate resulted in a higher NPV of nationalization than the counterfactual scenario, this financial analysis would support a mining policy for sustainable economic development in resource-rich countries. An economic upswing in the EV battery sector is on the horizon, while China has been the largest producer and recycler of batteries over the past decade, global battery production will diversify geographically (Torjesen, 2024), given the unbridled potential for revenue generation along the battery value chain, a shift towards higher value activities by countries in the global South that supply raw materials would offer significant economic gains.

The concentration of lithium in hard rock sources requires large amounts of spodumene ore to obtain economically significant quantities, resulting in substantial volumes of waste rock (Garcia et al., 2023). Regarding watercourses, lithium production from ores involves high water consumption. Lithium production from spodumene ores contributes significantly to water pollution.

In general terms, mining activity, in countries with substantial mineral resources, has been labeled as one of little added value creation, since it is limited to the export of minerals without further processing; this criticism has been based on the possible value chains seen prospectively and some macroeconomic impacts that this activity can generate; it is necessary to highlight the large value chain and impacts that mining suppliers can enable through an innovative technological process, which can be developed through the so-called agglomerations or clusters (Labó, 2021). To varying degrees, Australia and Chile are pursuing strategies based on exploiting and partially industrializing in their territories the mineral resources needed for the energy transition, specifically batteries that are essential for electric mobility (Bos et al., 2024).

Global demand for lithium-ion batteries is increasing, partly aimed at reducing the impacts of climate change through vehicle electrification and the energy transition in general; sustainable supply of lithium resources is at the basis of the development of new lithium-based energy industries and China accounts for 55% of global lithium resource consumption (Yuan et al., 2023).

China's industrial policy was to increase exports of renewable energy products to higher-income countries, such as Europe, as well as to Japan and the United States; throughout the 2010s, China increased its dominance in the solar PV and wind turbine markets by manufacturing high-quality, low-priced products (Bian et al., 2024).

China stands out for the high rate of processing/industrialization of exhaustible natural resources such as copper and lithium (Table 1), it also dominates the market for clean energy technologies based on its control of supply and value chains, according to Bian et al. (2024) China manufactures 78% of lithium-ion batteries from transition critical materials (TCMs) lithium, cobalt and nickel.

In terms of the energy transition, electrification is key and the rapid adoption of batteries, electric motors, and other technologies used in generation and distribution implies accelerated growth in the coming years; substantial growth is also expected for hydrogen and nuclear energy (Ku et al., 2024).

3.2. Impact of Copper and Lithium Industrialization on Environmental Sustainability

Mining extraction in territories and communities causes direct impacts on water: overuse, contamination, and deterioration of water sources (Coayla et al., 2024). Currently, there is an increasing preference for the consumption of products manufactured responsibly and with good socio-environmental practices, which generates pressures on the minerals market to establish a responsible supply chain, broadly speaking, supply chains comprise the entire economic structure of the global mining industry, from the extraction of raw materials to the points of consumption (Yurisch, 2022). Lithium salt production in China is still based on mineral extraction, which generates greater environmental damage than lithium production from brines; therefore, cleaner production systems from minerals are still lacking in China (Gu and Gao, 2021). Due to Chile's increasingly older and deeper copper mines, energy demand is expected to increase by 41% over the next 10 years (Vergara-Zambrano et al., 2022).

Decarbonization of the automotive sector will require major technological innovations and societal changes (Petavratzi and Gunn, 2023) such as increasing the size of the electric vehicle fleet, developing new technologies for powertrains, batteries, battery charging, fuel cells, power electronics, and vehicle bodies. While studying how to overcome these major challenges, mainly technical, it is also essential to assess the time required for their implementation.

Table 1: China: Mining and refining of TCMs

Material	% Reserves	% Extraction	% Processing	Needed for
Copper	3	9	42	Biomass, CSP, electrical storage, EVs, geothermal, grid networks, hydro, nuclear, PV, wind
Lithium	8	15	58	Electrical storage, EVs

Source: Bian et al. (2024)

Table 2: Copper and lithium demand correlations for electric vehicles

Correlations		
Demand for copper in the Net Zero Emissions by 2050	Demand for copper in the Net Zero Emissions by 2050	Demand for lithium in the Net Zero Emissions by 2050
Pearson's r	1	0.984**
P-value (bilateral)		0.000
N	7	7

**.The correlation is significant at the 0.01 level (bilateral)

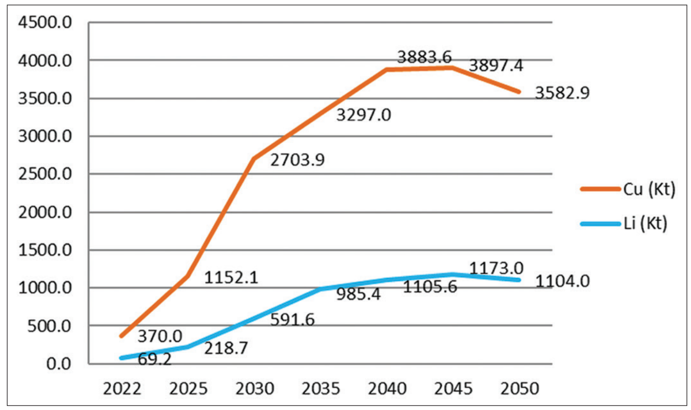
Lithium-ion batteries are used in an electronic products wide range (Rangarajan et al., 2022). According to Garcia et al. (2023), lithium is one of the main components of electric vehicles, cell phones, and laptops. Recovery of lithium from secondary resources is crucial to meet the growing demand (Garcia et al., 2023; Liu et al., 2019), and ensure the sustainability of the transition to the electrification of electric vehicles. In terms of sustainability, recovering lithium from waste such as spent lithium-ion batteries and wastewater is a potential approach to diversify Li extraction sources and make lithium production less resource-intensive. From the circular economy, reuse and recycling strategies for lithium-ion batteries are required to sustainably meet the demand (Ferrara et al., 2021).

The transition to green energy represents a significant structural change in the way energy is generated and consumed (Ghorbani et al., 2024), key drivers of the transition to green energy include (1) reduced environmental impact; (2) increased affordability of renewable energy; and (3) increased political support and subsidies.

Total copper and lithium demand in kilotonnes for the energy transition required for electric vehicles in the 2050 zero-emission scenario is projected to increase until 2045, after which it is projected to fall slightly (Figure 4).

A strong association was found between copper and lithium demands (in kt) for electric vehicles in the context of zero greenhouse gas emissions by 2050 (Table 2).

Figure 4: Total copper and lithium demand for electric vehicles in the 2050 net-zero emissions scenario (Kilotonnes)



Source: International energy agency

3.3. Social Development and Mining

Guzmán et al. (2023) showed that the social dimension of sustainability represents the smallest part of mining activities, while the economic and environmental sectors prevail. Furthermore, they argue that no piece of literature reviewed contains an analysis that addresses all three dimensions in a single paper. They also showed that only several attributes had been considered by the authors when examining the potential impacts that may affect the sectors within sustainable mining.

In analyzing the contribution of mining to national economies and development, Ericsson and Löf (2019) include indicators of social development: The Human Development Index (HDI). Governance: corruption, political stability, rule of law, government effectiveness, regulatory quality, voice, accountability, and inequality, the Gini coefficient. Eleven economies have moved up one step in the Gini development rankings, to the lower-middle, upper-middle, or high-income category, and the 20 low- and middle-income countries with the highest MCI-RW score in 1996.

The lithium brine resources in the lithium triangle (Argentina, Bolivia, Chile) in South America are immense (Petavratzi et al., 2022). In the lithium triangle, indigenous communities have historically been marginalized, and the rapid expansion of lithium mining may exacerbate these problems, as the motivation for expanding lithium mining is external to indigenous communities (Ghorbani et al., 2024). It is accepted that lithium drives the energy transition, however, there is an ethical dilemma, as the technologies allow curbing climate change and offer opportunities to lithium-rich countries such as Bolivia, extraction has socio-environmental consequences at the local level (Torjesen, 2024).

According to Romero-Carrión et al. (2023), concerning the socio-environmental component in South America, there are serious concerns about the environmental impacts adjacent to the areas of mineral extraction, particularly lithium; generating social conflicts, mainly over water use, the restricted participation of local people in decision-making in contracts with operating companies and the lack of state oversight of regulations that prescribe the prevention, control, reduction, and mitigation of negative environmental impacts, remediation and rehabilitation of exploited areas. Muñoz-Duque et al. (2020) mention that large-scale extractive activity generates benefits, but collaterally in its wake, it leaves negative impacts. As a result, 50% of mining projects have been canceled or suspended (Arias et al., 2022). Consequently, it is necessary to implement mining policies conducive to sustainable development, in which the benefits of mining go to local governments and are not absorbed by the central government. Sustainability in the rechargeable battery industry involves active participation and close collaboration between governments, manufacturers, recyclers, and end users (Yang et al., 2021).

4. CONCLUSION

In the world copper production of 22 million fine metric tons in 2023, Chile, the largest producer, produced five million MTF. Likewise, in 2023, Australia, the world's leading lithium producer, extracted 86 thousand metric tons of lithium. The industrialization of copper and lithium is linked to the energy transition, as in the electric vehicles manufacture that replace fossil fuels with clean energies, mitigating greenhouse gas emissions and contributing to environmental sustainability. China stands out for its high rate of industrialization of copper and lithium. Prospectively, there is a close association between the total demand for copper and lithium for electric vehicles in a zero-emission scenario by 2050. Copper production has a positive effect on economic growth on a global scale, although it is not significant in Africa and the Middle East.

The sustainable supply of lithium resources underlies the development of new energy industries and China accounts for 55% of global lithium consumption; this implies accelerated future economic growth. In South America, there are environmental impacts, adjacent to the mineral extraction areas, generating social conflicts such as in Chile and Argentina due to the extraction of lithium and other non-renewable resources, mainly due to the use of water. In contrast, in Australia, the world's leading producer of lithium for batteries, there are no signs of conflicts over lithium extraction, as in China.

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