



ISSN: 2993-8694

Advancements in  
Mining & Mineral Engineering

DOI: 10.33552/AMME.2026.01.000524

Iris Publishers

Case Report

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# Ensuring Mining Sustainability in a Profit-Driven Market

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Received Date: December 22, 2025

Published Date: March 09, 2026

## Abstract

Strong demand for minerals and metals and future price expectations drive the mining sector to increase production and to open new mines, often without considering that new projects and production must adequately compensate not only for their own investments, costs, dividends, and various other expenses, but also for the presumable use, damages, and degradation of flora, fauna, soils, water, and other natural resources, including the extraction of the in-situ minerals that are at the origin of the business, natural assets all of these that inalienably belong to the patrimonial heritage of a region or country for its own development.

Several institutions and organizations have established best practices and standards to safeguard biodiversity and environmental sustainability (OECD, Rural 16.06.2025). Unfortunately, these sound principles, regulations, and other standards are not always strictly followed. Some of these regulations are, in practice, quite lax, and the consequences become apparent years later. Therefore, countries that produce critical minerals, such as copper, lithium, cobalt, nickel, rare earth elements, and others, require more objective criteria for regulatory compliance.

Biodiversity and sustainability must be strategically managed, and for this, both must be measured and controlled. Decades ago, some natural capital components were difficult to measure; damages to nature were always far from being estimated. Intangible assets, such as in-situ minerals in the ground, could not be valued; as a result, key natural capital components could not be recognized. Today, any component of nature can be valued at its current status.

This paper shows that most of the natural capital components can be valorized, even the intangible mineral resources deposited at depth or the degradation of the tourism sector in a region due to landscape alteration, noise pollution, and loss of biodiversity. Although a sustainable mineral business strategy applies to any metal, the analysis will be based on some critical minerals in high demand today. The case dealing with an ecosystem of lithium-bearing brine deposits in the Andes Mountains will show how the balance between major capital investment and natural capital can be measured and controlled.

**Keywords:** Net-Zero Scenario; Metal Demand; Metal Prices; PIB; Sustainability; Biodiversity Index; Natural Capital; Lithium Economics

## Introduction

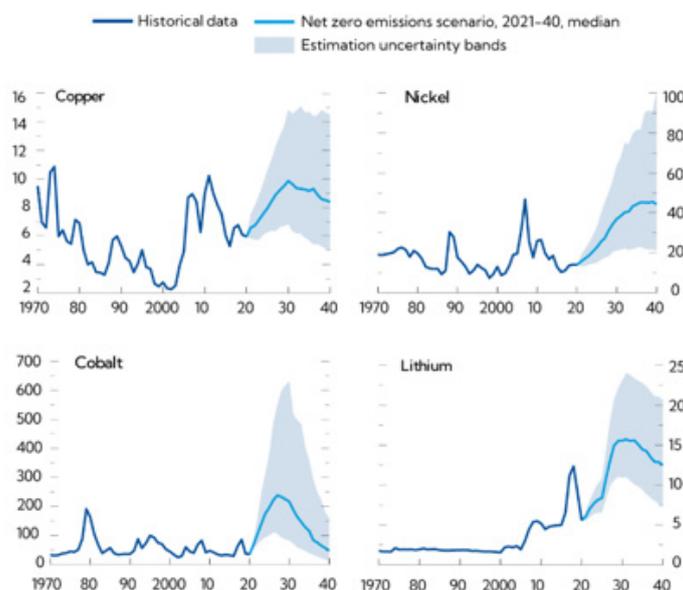
### Approaching the net-zero scenario

Energy transition is demanding a new range of mineral resources: scarce, difficult to find, highly complex to extract, with high market expectations, and spatially distributed among a few countries. While this transition is progressing slowly, geopolitics is intertwined with it, raising the prospects for conflicts between countries that need them to further increase their power. These

minerals, considered strategic by the countries that possess them or critical by those that need them for security reasons and their advanced technologies, are currently a maximum priority for mining companies.

Some of these metals could reach historic highs in the context of a future scenario such as the so-called net-zero scenario, tentatively projected to develop around 2050 (Figure 1).





**Figure 1:** Uncertainty Bands Associated With A Few Critical Minerals.

**Sources:** international Energy Agency (IEA); Schwerhoff, G. (2019) and Stuermer, M. (2020); US Bureau of Labor Statistics; US Geological Survey; and IMF staff calculations. Prices are adjusted using the US consumer price inflation index. The scenarios are based on a metal-specific demand shock. Band show 40% highest posterior density credible sets.

As hinted above, the sustainability required for a net-zero scenario necessitates financing not only to return the due dividends to the investors but also to compensate for the environmental impacts of these businesses on the mine ecosystems. These impacts include:

- Carbon footprint that measures total greenhouse gas emissions (CO<sub>2</sub>e)
- Water footprint that evaluates total water used during the whole process.
- Energy consumption that tracks the total energy use (kWh) or joules.
- Waste generation that assesses the total amount of waste produced.
- Biodiversity degradation that assesses damages to flora, fauna & organisms.
- Social impact that assesses the effects on community well-being.
- Life cycle assessment that values land use throughout its life cycle.

- Sustainability reports such as the GRI initiative or the SASB account report.
- Sustainable development goals that are aligned with those of the United Nations.
- In-situ mineral appraisal values the present status of in-ground resources.

These impacts reflect the eventual damage, deterioration, disruption, and any other detriment that could affect the capital provided by nature, the environment, and communities, including the mineral resources that will be extracted and consumed to generate business.

The projected production demand to 2050 [1], which increases copper demand from 25 million metric tons to 36 million metric tons; lithium (Li<sub>2</sub>CO<sub>3</sub>) from 1.2 million metric tons to 6.5 million metric tons; cobalt from 0.33 million metric tons to 0.60 million metric tons; nickel from 5.8 million metric tons to 9.5 million metric tons; and graphite from 3 million metric tons to 7 million metric tons, in addition to price expectations, leads us to anticipate a new price super cycle, Figure 1.

This upward trend in demand for critical minerals is accompanied by a rise in prices. It is in these types of cycles that mining companies merge, mineral exploration intensifies, mines expand, and new mines are launched or stretched to such an extent that, according to Bloomberg calculations, the amount of minerals and metals in a net-zero scenario by 2050 implies the extraction of some 6 billion metric tons of metals at an approximate cost of USD 2.1 billion [1].



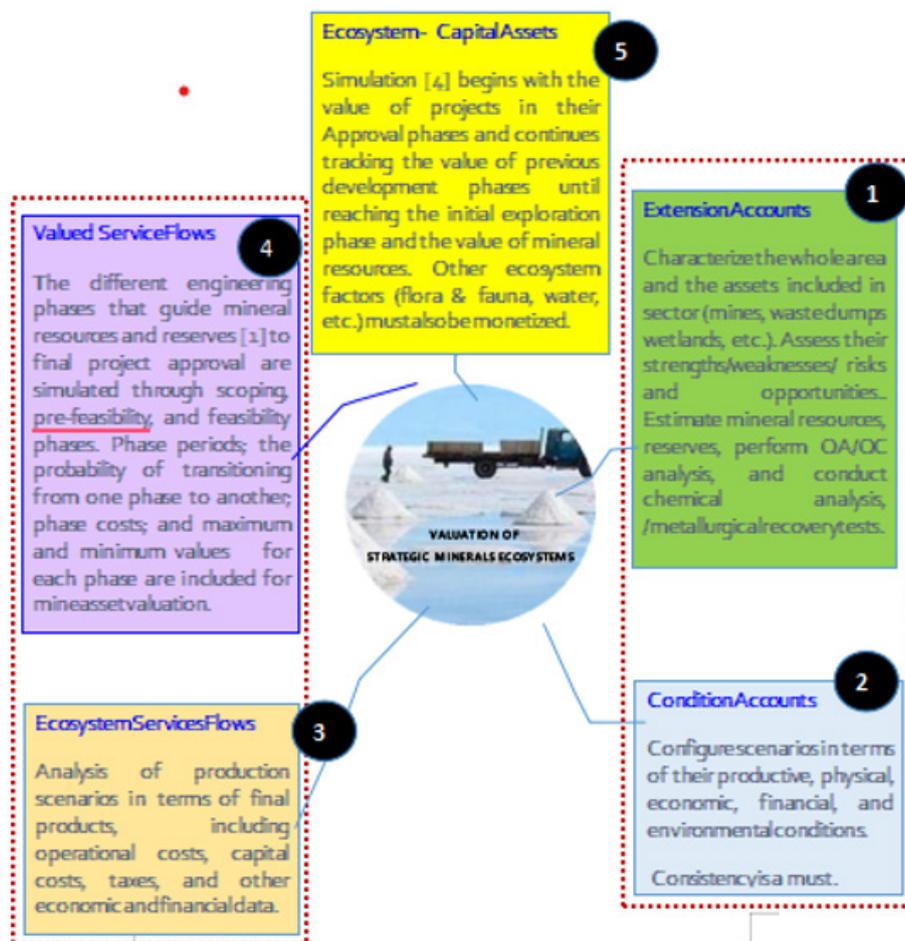


Figure 3: Components of the SEEA

It is important, in the case of a mining ecosystem, to clearly establish the economic values for all the factors included. Criteria and methodologies must be entirely traceable, verifiable, and reliable. Valuation admits formal calculations, historical information, scalable data, and any other techniques to the condition of using material information; that is, information generated by facts associated with a spatial and temporal context.

On the other hand, the GRI, as the Global Reporting Initiative, is a non-profit organization that operates internationally. The GRI has developed guidelines for sustainability reporting, in which companies are responsible for reporting the impacts of their businesses on society and the environment. The GRI standards promote the disclosure of comprehensive sustainability information without restrictions based on industry, size, or geographic locations. The GRI understands that sustainability reports are a determining factor in achieving societal objectives.

GRI standards can be universal (for any type of organization), sectorial (for specific areas of the industry), or thematic (to address specific issues such as the environment, human rights, and others).

Like any other compliance standard, the GRI has requests or requirements that must be met to achieve conformity. It is important to understand that the GRI standards are based on concepts (such as the impacts of activities, due diligence, stakeholder engagement, and material information) and principles (such as accurate, balanced, clear, comprehensive, unbiased, substantiated, time-bound, and verifiable information).

In contrast, the SEEA is a fully quantitative report to be included in a country's National Accounts or a region's Regional Accounts through valuations of all assets included in the mining ecosystem, so that accounts and flows are clearly reflected in the gross domestic product of either the country or the region.

While these standards are very necessary, useful, and informative, it would be interesting to establish specific measures or rankings that would allow us to know whether or not mining projects honor the due compensation for both invested capital, through NPV, and natural capital through a minimum required value (threshold or cut-off).

## Value added. Value destroyed

### A biodiversity index: the breaking point between rationality and squandering.

Just as in everyday life, a project or business must pay or compensate for the services received for the development of their activities. In this case, the services received by a project come from the machinery, equipment, and other goods (investment capital) and from in-situ mineral resources, flora/fauna/water, and other factors (natural capital).

Among the most relevant natural factors used by a critical mineral ecosystem project are the mineral resources to be extracted, the surrounding flora and fauna, the extended soils, and the consumed water. In the case of critical minerals, other factors may exist, such as the impact on tourism, dust generation, the emission of chemical gases, and others. The following is a summary of a case study in which an index is established for lithium projects

arising from the ecosystem of lithium brine deposits located in the Andean Altiplano [5]. This index constitutes the minimum threshold for projects or businesses generating a given Net Present Value (NPV), and adequately compensating also the services provided by nature, represented in this case by the five factors mentioned in the previous paragraph. The whole ecosystem included 111 lithium-bearing brine salars distributed between Majors (2), Mediums (78) and Minors (31) all of which require a cumulative investment capital of USD 72.100 million for an annual production of 2.527.500 tons of lithium carbonate during a period of 20 years.

- Mineral assets must be valued according to their mineral resources and reserves through a process that, starting from the project's NPV, works backward in time, sequentially valuing all phases prior to that estimate. In this way, 111 brine deposits were valued, grouped into three classes according to their production capacity from the feasibility phase back to the origin: the value of the in-situ mineral resources, Figure 4.

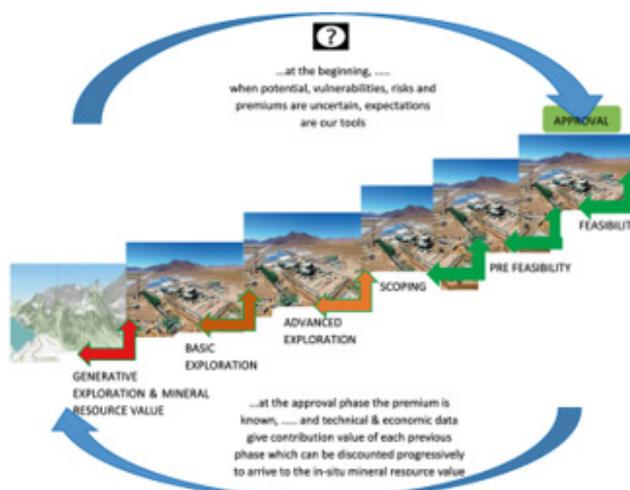


Figure 4: Representation of Valuation of a Mining Asset.

- Three NPV scenarios were calculated using the three production capacity classes (Major/Medium/Minor) and three lithium carbonate prices: USD 10,000/t, USD 25,000/t, and USD 50,000/t. Based on these prices, the corresponding NPVs for each production class were accumulated, resulting in USD 28.600 millions for the Minors, USD 249 millions for the Mediums, and USD 636.000 millions for the Majors. These values were then used and traced back to timely determine the value of the mining assets, in the three classes, at each stage of their development, from the NPV's approval phase until reaching the original in-situ resource value. Figure 5 shows the assets value for the Majors and Medium deposits, considering a price of USD 25,000/t Li<sub>2</sub>CO<sub>3</sub>.
- Based on lithium carbonate prices of USD 10,000, USD

25,000, and USD 50,000 per ton, the cumulative economic values for the in-situ lithium resources in each group is obtained: for the Minors the value is USD 432 millions, for the Medium group is USD 7.050 millions, and for the Major group is USD 17.964 millions.

- Flora and fauna were valued considering a study of a small section of the lithium ecosystem [6], assuming it as a "pilot project," and scaling it up to cover the entire 400.000 km<sup>2</sup> area.
- The study area covered approximately 76 km<sup>2</sup>, encompassing 1.357 flora and fauna topics. Of these, 1.223 were conducted by private institutions and 134 by public institutions, focusing on themes ranging from water and sediment quality to

aquatic biota and soil quality. Studies also included fluvimetry, hydrogeology, meteorology, wetlands, vegetation, and other related aspects. The cost of repairs and restorations in the pilot

area reached approximately US\$8 million, contributing to a total cost of USD 47.400 Million for the entire Lithium Plateau area. Figure 6

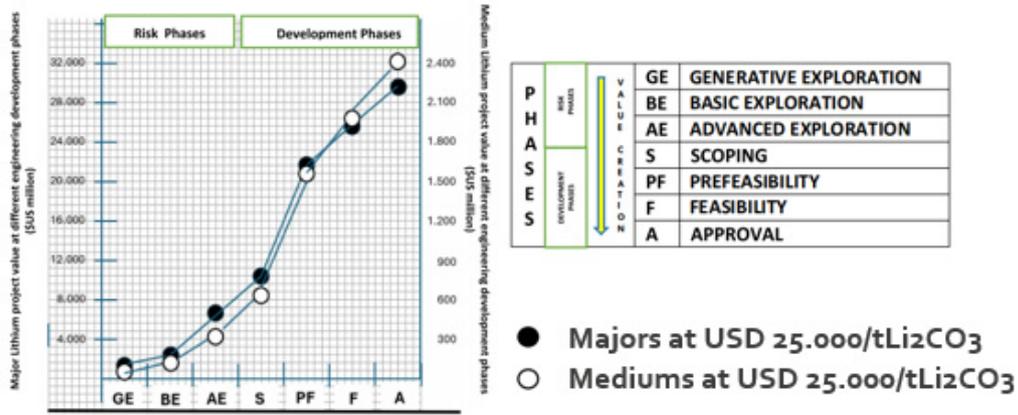


Figure 5: Value of lithium-bearing brine salars Valuation of Mineral Assets.

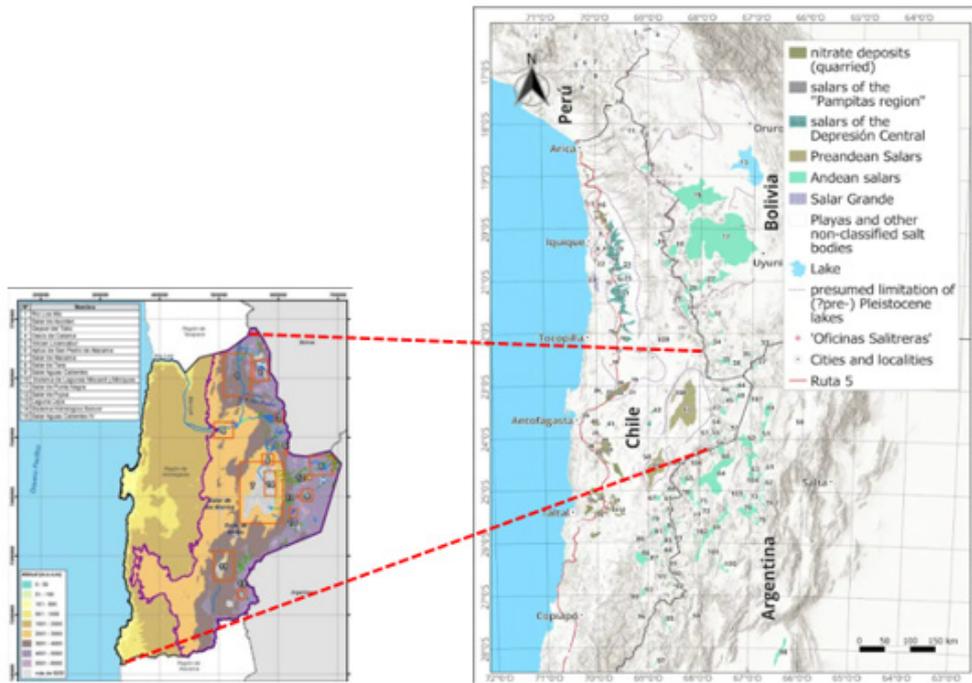


Figure 6: Map showing the lithium ecosystem in the Altiplano Andino (right) and the region from which the pilot study was taken (left).

- Soils are also altered due to the extraction of mineral resources through earth-moving, road construction, and other infrastructures. Assigning \$4.000 per hectare and an average of 400 hectares of altered soil per deposit, the value of the degraded soil in the Altiplano reaches US\$160 Million.
- Water consumption is a complex issue. As statistics indicate a wide range of consumption is due to brine content, altitude,

and site conditions. However, among the most well-known ranges, consumption reaches up to 2,000 m<sup>3</sup> of water per ton of lithium carbonate [7]. As a result, total water consumption in the entire Lithium Plateau, using current technology, may reach 9,100 Mm<sup>3</sup> over a 20-year period. Assuming a price of US\$4.50 per m<sup>3</sup> of water, the capital provided by water reaches approximately USD 41.000 million. Figure 8

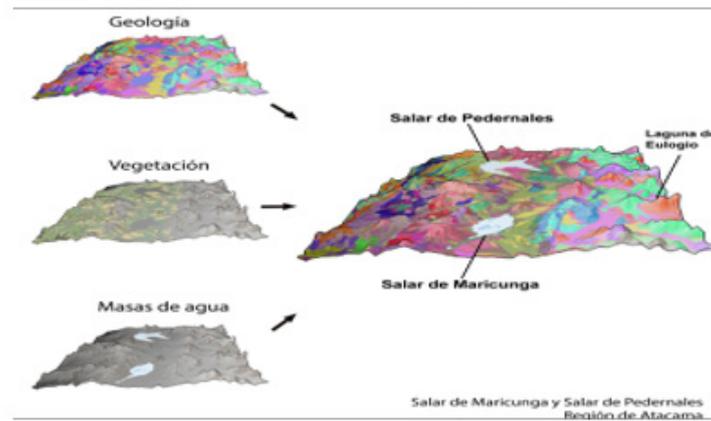


Figure 7: A GIS application allows identification of geological, vegetation, and water in a lithium ecosystem in the Altiplano Andino.



Figure 8: Water is one of the most important factor in a critical mineral ecosystem.

### As A Summary: Putting Numbers Together

Table 1: Valuation results of the in-situ lithium resources, soils, flora & fauna, and water consumption in the lithium ecosystem in the Alto Andino (Million USD)

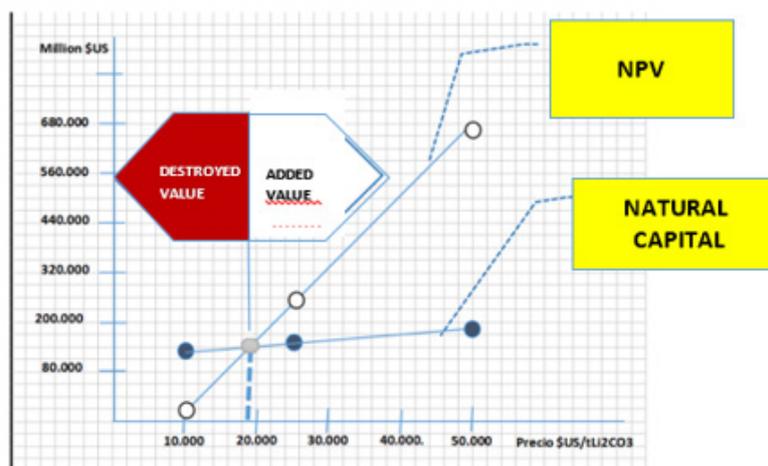
Natural Capital Factors	Prices USD/tLi2CO3		
	10.000	25.000	50.000
Lithium resources	432	7.050	17.964
Soils	160	160	160
Flora & Fauna	47.400	47.400	47.400
Water consumption	41.000	41.000	41.000
Total, Natural Capital	89.992	95.610	106.524

Table 2: Valuation comparison of economic results between the lithium ecosystem's natural capital, the business' investment capital, and the business total Net Worth (NPV) (Million USD).

Cumulative Capital Components	Source	USD 10.000 USD 25.000 USD 50.000		
		Ecosystem Value in Million USD		
Natural Capital	Table 1	89.992	95.610	106.524
Investment Capital		72.100		
NPV Lithium Business		28.600	249.000	636.000

• Figure 9 shows, on average, that at or above a price of USD 18.000/tLi<sub>2</sub>CO<sub>3</sub>, the extraction and processing of lithium resources can adequately compensate investors, the government, and the natural capital associated with the

mining ecosystem. With lower values of this index, some of the aforementioned components are not adequately compensated. Unfortunately, lithium carbonate prices in recent years have been well below this index.



**Figure 9:** Businesses NPV and Natural Capital Value in the Lithium salars Plateau as a function of the Li<sub>2</sub>CO<sub>3</sub> price . Figure shows the breaking point: at USD 18.000/t Li<sub>2</sub>CO<sub>3</sub>.

## Conclusions

- The surge in global demand for metals in recent years, driven by the pursuit of net-zero emissions, is leading to substantial price increases in raw materials. This, in turn, is fueling production expansions, mining mergers, intensified exploration, and increased mine extraction.
- Amid this economic boom, particularly for mining companies and producing countries, current global growth appears stagnant, hovering between 2% and 3% per year. This poses challenges for companies and governments in their long-term planning due to market volatility, instability in international trade, and geopolitical processes that can influence not only the efficient use of investment efforts but also the rational, timely, and sustainable use of the natural resources involved in these businesses.
- Today, two global standards protect environmental sustainability and biodiversity. The United Nations standard, known as SEEA, involves quantifying the economic flows, accounts, and evaluations of each investment item, as well as each component of natural capital associated with a mining ecosystem, in monetary terms, so that these are fully reflected in the National Accounts. The other standard is the GRI, which companies voluntarily report to society as a result of their business activities at a global, sectorial, or thematic level.
- To illustrate how biodiversity can be ranked in order to make transparent whether the results of a given business

are capable of adequately compensating its investors and the State, as well as compensating for the services provided by the natural resources consumed, degraded, or damaged, the results of an application carried out in the lithium salt flats located in the High Andes were presented.

- In a period in which there will be a temptation to extract resources without meeting minimum standards, avoiding extractivism, which considers nature simply as a commodity, a biodiversity index, such as the one proposed in this paper, has the guarantee of separating rationality from wastefulness.

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