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Renewable Energy and Energy Storage Value Chains in Latin America and the Caribbean

Francisco Parés Olguín Pablo Busch

Editors:

Natascha Nunes da Cunha Juan Roberto Paredes Carlos G. Sucre

Inter-American Development Bank Energy Division

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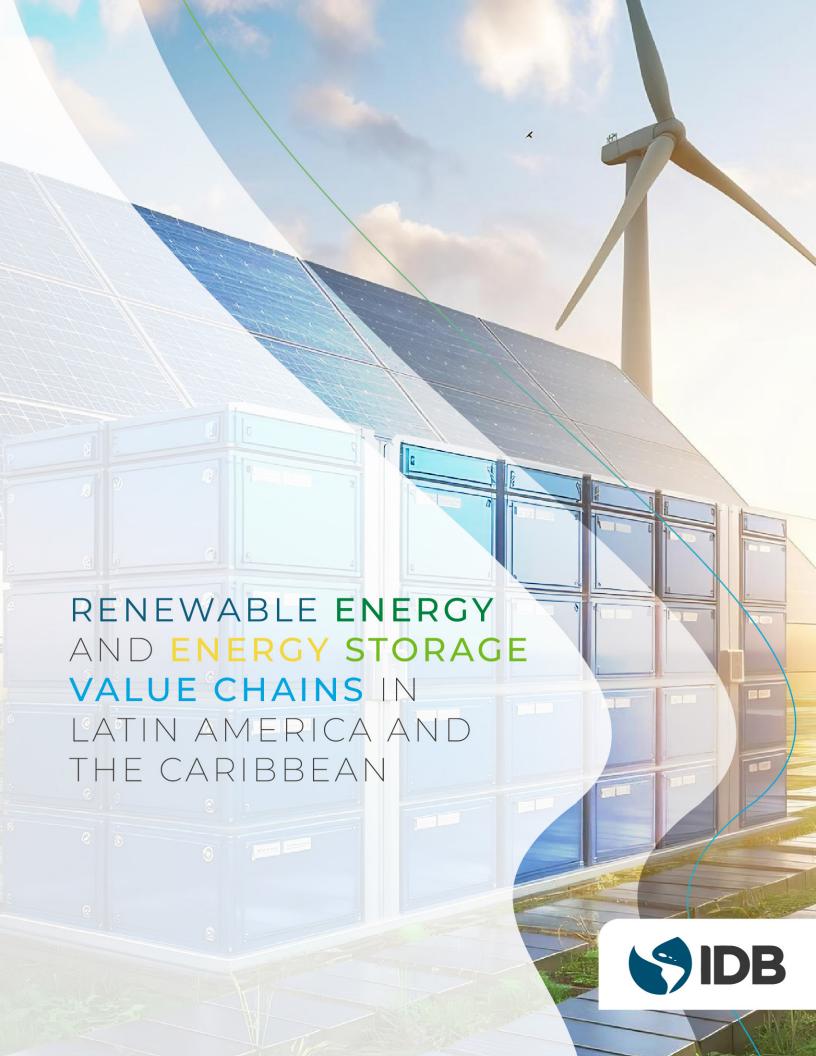
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This report is part of the knowledge agenda developed by the Energy Division of the Inter-American Development Bank that aims to develop new knowledge products and technical assistance programs for Latin American and Caribbean countries. The knowledge products generated are intended to inform, guide and offer a menu of recommendations to policy makers and active participants in energy markets, including consumers, utilities and regulators.

The report was prepared under the overall direction of Marcelino Madrigal (Chief, Energy Division) and coordinated by Natascha Nunes da Cunha, lead mining specialist, Juan Roberto Paredes, senior clean energy specialist, and Carlos Sucre, mining sector specialist. The authors of the report are Francisco Parés Olguín and Pablo Busch of the University of California at Davis.

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NARODOCTION

The global energy transition presents important opportunities for sustainable growth in Latin America and the Caribbean (LAC), opening avenues to continue its development and contribute substantially to global decarbonization efforts. Globally, the energy sector generates 73.2% of greenhouse gas (GHG) emissions (Ritchie, 2020). Achieving the goal of limiting global temperature increase to 1.5°C requires rapid technological development and infrastructure expansion (IEA, 2024). In the intensive adoption phase, the transition implies changing from a fossil fuel-intensive energy system to a mineral-intensive system (Zhang et al., 2023), which will necessarily generate changes in the global configuration of energy system value chains.

Three key technologies for the global decarbonization of the energy sector are the adoption of solar photovoltaics, wind energy and lithium batteries for electric vehicles (EVs) and other uses. These three technologies have global supply chains, which generally consist of the following 5 stages (see Figure 1):



Each technology requires different inputs and raw materials, especially minerals, and each stage has different levels of complexity. Solar panels require, among other minerals, silicon, copper and zinc; wind turbines require copper, magnesium, zinc, nickel, iron, aluminum (bauxite) and rare earths; and batteries require lithium, nickel, cobalt, copper, magnesium, graphite and aluminum (bauxite). Given that global decarbonization plans require the massive use of these technologies, several studies have concluded that global demand for these so-called **critical minerals** will increase multiple times by 2050. Estimates show that over the next 30 years demand for lithium increases between 5 and 22 times, nickel between 2 to 9x, cobalt between 2 and 3x, manganese between 7 and 29x, silicon between 2 and 3x, rare earths between 3 and 7x, graphite between 2 and 6x, copper between 2 and 16x, iron 26x, and zinc between 2 and 3x times (IEA, 2023a; IEA, 2024; BNEF, 2023). This exponential growth in demand presents a significant opportunity for industrial development at each stage of the value chain, such as in the extraction of raw materials in countries with significant mineral reserves, but also in higher value-added stages such as refining and the manufacture of technological components.

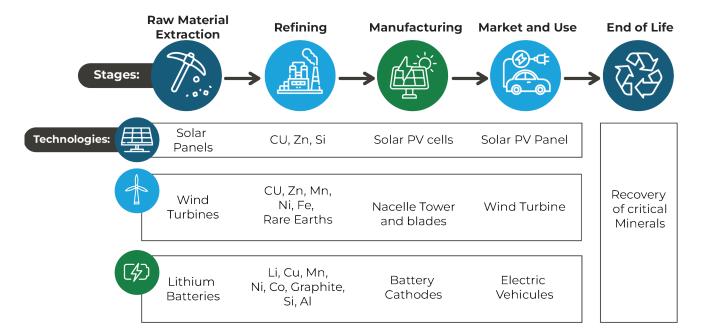


Figure 1 - Stages of the Value Chain for the three key technologies for the global energy transition. The main minerals, components and products for each technology are indicated. Source: Own elaboration.

LAC has a comparative advantage in that it has significant reserves of minerals that are critical for the energy transition (see Figure 2). More than US\$50 billion in annual profits are estimated for LAC by 2050, mainly in Chile and Peru, just from the demand generated by the energy transition for minerals such as copper, zinc and lithium (IDB, 2022). Multiple countries in LAC have significant mineral reserves. Nearly half of the lithium reserves (and more than half of the resources') are contained in the so-called Lithium Triangle formed by Argentina, Bolivia and Chile. Chile, Mexico and Peru have more than one third of the world's copper reserves. Mexico and Peru contain 16% of global zinc reserves. Additionally, Brazil holds between 12 and 26% of the world's reserves of graphite, iron, manganese, rare earths and nickel. Jamaica and Brazil have considerable reserves of bauxite (16%), the main raw material used to obtain aluminum. Brazil also participates in the extraction of silicon, the main component for the manufacture of solar panels. However, for many minerals, LAC's share of global production is much lower than its share of global reserves, indicating that there is room and opportunity to expand mining in the region. The first step for LAC in its strategy to deepen its participation in the decarbonization technology value chain is to promote greater, more efficient and more responsible extraction of these critical minerals.

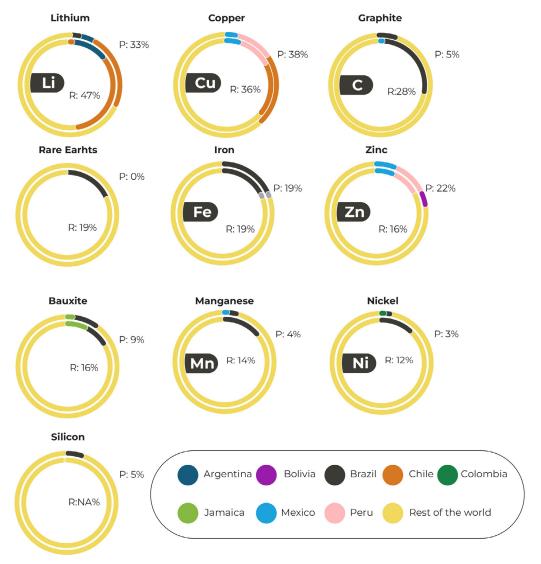


Figure 2 - Concentration of reserves and production of critical minerals in LAC. R: Percentage of global reserves present in LAC, P: Percentage of global production present in LAC. Source: USGS 2024 Mineral Commodity Summaries (USGS, 2024).

¹ The term resource refers to the total amount of ore that exists in a deposit that is potentially feasible to extract, and reserves refers to a subset of the resource that meets physical and chemical standards for its extraction to be classified as economically feasible (USGS, 2023).

LAC can and should leverage its comparative advantages in mineral reserves and raw material extraction to expand into mineral refining, such as refining copper, silicon metal or lithium carbonate, products with higher added value. The initial step to advance in refining is to increase raw material production, with greater efficiency in mineral capture and extraction capacity at mining sites. Similarly, through national strategies or intra-regional cooperation, LAC can develop a decarbonization technology industry at more advanced stages of the value chain, promoting the production in the region of solar panels and cells, wind turbines, or lithium battery cells, and thus capture greater value added in the region. Currently, LAC's preponderant position in mineral reserves and extraction does not translate into a dominant position in refining, where China plays the dominant role. For example, Chile leads in copper extraction (with ~23% of world production), but only processes ~8% (China leads with 44% of copper processing) (USGS, 2024), while for lithium it extracts and processes about 25% of world production (Australia leads in lithium extraction with ~45%, and China leads in lithium refining with ~65% worldwide) (IEA, 2024). Chile led the world in copper refining until 2005,

before the exponential rise of China (CESCO, 2020). The country's loss of leadership in copper refining is explained by the emergence of more competitive smelters in China (with significant subsidies), leading to the prioritization in Chile of the extractive part of the business that was more profitable (CESCO, 2020). This required new investments given the deterioration in the quality of its mineral deposits, together with greater environmental and social demands (CESCO, 2020). Brazil, despite having 12% of the world's nickel reserves, supplies only 2.5% of the world's nickel demand, while Indonesia extracts 50% (USGS, 2024). China's dominance at this stage of the value chain (IEA, 2023a) is explained by the following comparative advantages (Sanin et al., 2023): high local demand for EVs and solar panels, low energy and labor costs, economies of scale in production and technological availability. LAC can close gaps in these areas by strengthening local industry through public procurement, taking advantage of the development of new renewable energy resources with low cost and environmental impact, promoting training and technical education to generate skilled labor. and strengthening trade and technological cooperation between countries in the region.



To capture the economic benefits of the energy transition, LAC needs to overcome several barriers in terms of intra-regional cooperation, financing, adequate regulation and mitigation of socio-environmental impacts. In the first stage of the value chain: extraction of raw materials, LAC has a privileged position in concentrating critical reserves, especially copper and lithium, and labor and industries historically specialized in mining. The limiting factor for mining can be conflict with local communities and environmental impacts, so it is vital that industry and regulation move towards a social mining license to operate, mitigating associated environmental impacts and generating strategic alliances with local communities. Although LAC countries have public policies aimed at encouraging the energy transition and industry, efforts are disjointed. Each technology requires multiple minerals in its value chain, so collaboration between countries in the region is key to developing more complex industries with greater added value, such as the production of solar cells or battery cathodes.

This document provides a critical analysis of LAC's role in the global energy transition and presents recommendations to take advantage of the development opportunity that exists. The paper addresses each of the five stages of the value chain, focusing on three key technologies: solar panels, wind turbines and lithium batteries. For each stage of the value chain, opportunities, challenges and recommendations are defined for LAC, focusing on Argentina, Bolivia, Brazil, Chile, Colombia, Ecuador, Jamaica, Mexico, Panama, Peru and Venezuela, since these countries have significant mineral reserves, mining industries and/or more advanced industries that could participate in the manufacturing stages of the value chain. This document is based on four recent reports prepared by the IDB, which describe the efforts and work carried out by the bank to

encourage and promote the development of LAC in this area. The main messages of the document

 The global energy transition presents an important economic opportunity for the development of LAC, while the production of these technologies contributes to the global fight against climate change.

are summarized as follows:

- LAC unique has а advantage concentrating most of the world's critical minerals, and because of its competitive position in extraction costs for copper, iron (Spano et al., 2021) and lithium (Greim et al., 2020; Ambrose and Kendall, 2020). Countries in LAC with significant mineral reserves are Argentina (lithium), Bolivia (lithium), Brazil (graphite, iron, manganese, rare earths, nickel, bauxite and silicon), Chile (lithium and copper), Jamaica (bauxite), Mexico (copper and zinc) and Peru (copper and zinc). LAC can capture greater benefits in the value chain by exploiting and expanding its comparative advantages: mineral reserves, skilled labor, strategic positioning as a trade ally of the United States and Europe, and access to port infrastructure for exports. Technical training and education are key to developing more complex and higher value industries.
- Mining extraction requires achieving and maintaining a social license to operate, so the industry needs to go beyond national legislation on environmental and social issues.
- Strategic alliances between countries in the region are key to competing globally in more complex stages of the value chain.
- For the **end of life,** the absence of a comprehensive regulatory framework generates deficiencies in the valorization of the resource, lack of private investment, and encourages informality. A long-term vision to develop the recycling industry would avoid environmental impacts and provide a sustainable recovered minerals industry over time.



RAW MATE

2.1 Opportunities

Concentration of world reserves

LAC has a great competitive advantage in the extraction of raw materials thanks to the fact that it concentrates most of the world's reserves of minerals required for the energy transition (see Figure 2). For example, for the manufacture of solar panels, LAC has 36% of the world's copper reserves, 16% of zinc reserves and 5% of silicon metallurgy production. For wind turbines, in addition to copper and zinc reserves, LAC has 14% of the world's manganese reserves, 12% of nickel, 19% of iron and 19% of rare earths. For lithium batteries, in addition to copper, manganese and nickel reserves, LAC has 47% of the world's lithium reserves, 28% of graphite and 16% of aluminum (bauxite). This shows the existence of mineral resources in LAC required to produce energy transition technologies.



About half of the world's lithium reserves are concentrated in Argentina, Bolivia and Chile.

These reserves are not only high in quantity but also of high concentration, low extraction seet.

These reserves are not only high in quantity, but also of high concentration, low extraction cost and lower environmental impact than other global lithium reservoirs (Sanin et al., 2023). This is because the reserves in LAC occur mostly in brine deposits, which are reservoirs of water with mineral salts, such as sodium and lithium. The extraction process consists of pumping the brine, evaporating liquid to concentrate minerals and selecting minerals through chemical processes, such as the addition of agents to remove magnesium (Sanin et al., 2023). LAC also has lithium in rock deposits, such as Grota do Cirilo in Brazil, or sedimentary deposits of volcanic origin, such as in Sonora Mexico. Production from other types of deposits, such as rock formations, is done with more traditional mining processes and generally with higher costs and impacts (Greim et al., 2020; Ambrose and Kendall, 2020). Despite the higher cost of rock deposits, Australia currently dominates global lithium mining. The IDB report From Lithium to Electric Vehicles in Latin America and the Caribbean (Sanin et al., 2023) contains a more detailed analysis of the lithium value chain and its potential development in LAC.

LAC has historically led copper extraction, mainly in Chile, Mexico and Peru, and its extraction represents the largest gain in mineral supply for future energy transition technologies (IDB, 2022). Building on an already high volume of current demand, copper will continue to be a key mineral for the energy and technology transition, given its fundamental use as an energy driver, so significant growth is expected in the future. LAC's long experience in copper extraction, together with the large amount of reserves it still has, presents a comparative advantage to continue exploiting this mineral in the region. Supplying copper for the growing demand that will be generated by the energy transition means benefits for producers in the region of more than 40 billion dollars per year by 2050 (IDB, 2022). Therefore, LAC should prioritize maintaining its world leadership in copper extraction and expand its participation in copper refining.

In addition to lithium and copper, LAC has significant reserves of minerals for the manufacture of lithium batteries, such as nickel, graphite and manganese. Reserves of these are found mainly in Brazil, with a smaller proportion in Mexico. For each, the reserves relative to the world total are greater than their relative production, indicating an untapped opportunity in their extraction. Several studies have projected an exponential growth in demand for lithium batteries (IEA, 2023a; IEA, 2024; BNEF, 2023), which represents a unique opportunity to extract nickel, graphite and manganese in LAC and promote the regional production of lithium batteries.

LAC also has significant reserves of other minerals and inputs required for solar panels and wind turbines. For solar panels, there is availability and existence of production chains of primary resources, such as silicon, copper, aluminum; and other inputs such as glass and ethylene-vinyl acetate (IDB, 2023; Solar Cluster, 2015). For wind turbines, LAC has skilled labor, availability and existence of production chains for primary resources, such as rare earths (IDB, 2023).

Exponential growth in future demand for minerals

LAC's mineral reserves are essential to meet the projected demands of global decarbonization plans (see Table 1). Mineral reserves represent not only an economic opportunity for the region, but also an opportunity to collaborate globally in mitigating climate change and reducing its impacts in the region (IPCC, 2022). Table 1 shows mineral production to 2023 and known mineral reserves in LAC, along with cumulative demand projections from the IEA and BNEF (IEA, 2023a; BNEF 2023). From this, we calculate the ratio of LAC reserves to global demand, i.e. the portion of cumulative demand to 2050 that can be supplied by LAC. For certain minerals, LAC reserves are more than sufficient to meet global demand, such as manganese (LAC reserves are between 7.8-8.9x global cumulative demand), rare earths (10.5x) or copper (1.4-2.1x). Global demand for other minerals, such as graphite (0.66-0.92x), lithium (0.39-0.54x), nickel (0.20-0.28x) and zinc (0.83x), exceeds LAC reserves. This reinforces two key points:

- Demand for materials to decarbonize will grow exponentially, which provides good incentives and guarantees for the raw materials supply industry. The current window of opportunity offers unique demand conditions for mining projects for critical minerals, such as lithium, graphite and rare earths.
- O2 LAC can develop economically by extracting these raw materials and contributing to the decarbonization of the planet, thus helping to mitigate climate change and its impacts. The goal of limiting the temperature increase to 1.5°C will avoid significant costs for LAC, given that it is a region that is highly vulnerable to climate change.

Accumu	lated	demand

Ratio of LAC Reserves to Cumulative Demand

Mineral	Production 2023 LAC	LAC Reserves	IEA 2023-2050	BNEF 2020-2050	IEA	BNEF
Copper Graphite Lithium Manganese Nickel Silicon Rare Earths Iron	8.35 0.08 0.06 0.84 0.09 0.2 0 311.6	363 77 13 275 16 21 16,200	973 395 30 44 154 54	262 84 33 35 58	0.37 0.20 0.43 6.19 0.10	1.39 0.92 0.39 7.86 0.28

Table 1 - Production and reserves in LAC, together with global cumulative demand for different critical minerals, all in millions of metric tons. Cumulative demand is presented according to different projections, with different time periods and minerals considered. The ratio between LAC reserves and global cumulative demand is indicated for each demand projection. (a): IEA Net Zero 2050 scenario. Cumulative demand from all sectors of the economy (calculated by linear interpolation of demand between 2023, 2030, 2035, 2040, 2045 and 2050). (b) Net Zero Scenario Electric Vehicles outlook - Lithium batteries only. Source: (USGS, 2024; IEA, 2024; BNEF 2023).

2.2 Challenges

High reserves do not necessarily translate into high production

The added value of critical minerals is not obtained from the amount of reserves, but must be leveraged from a greater and better extraction of this raw material. Despite having a significant percentage of mineral reserves, LAC tends to produce less than the rest of the world (see Figure 2). The minerals with the greatest difference between world reserves and global production (in 2023) are graphite (28% of global reserves, and only 5% of global production), manganese (14% reserves, 4% production), rare earths (19% reserves, 0.02% production), nickel (12% reserves, 2.5% production) and bauxite (16% reserves, 9.3% production). To a greater or lesser degree, for each of these minerals, LAC has not captured the economic opportunity for their exploitation.

For most of the critical minerals present in LAC, the current level of production allows the extraction of reserves to continue for more than 100 years (see Table 2). Mineral reserve is a geological and economic concept that represents the amount of ore that is economically feasible to extract given current technologies and market conditions (USGS, 2023). Given that technological development and markets change over time, reserves are not static but dynamic as economic incentives and advances in exploration and mining technology are generated, thus increasing reserves over time (Castillo & Eggert, 2020). For example, world lithium reserves have increased 10-fold in the last 25 years (USGS 2024; USGS, 1996). This reinforces the point that a reserve extraction rate of less than 1% per year, or 100 years of remaining exploitation, is too low to take advantage of the opportunity given the future growth in demand for these minerals. LAC currently mines little lithium, graphite and rare earths relative to its level of reserves. Brazil presents a unique case of low exploitation of its reserves of graphite, rare earths, bauxite and nickel. These countries could focus efforts on increasing mineral exploitation. Some LAC countries exploit their reserves at rates close to 5% per year, as with zinc in Peru and Mexico, manganese in Mexico or nickel in Colombia. To maintain current production levels, these countries must invest in the exploration of these mineral resources.

Mineral	Country	Production 2023 [million tons]	Reservations [million tons]	Remaining years of operation
Lithium	Brazil	0.0049	0.39	80
	Chile	0.044	9.3	211
	Argentina	0.0096	3.6	375
Copper	Chile	5	190	38
	Peru	0.6	120	46
	Mexico	0.75	53	71
Graphite	Brazil	0.073	74	1,014
	Mexico	0.002	3	1,550
Rare earths	Brazil	0.00008	21	262,500
Iron	Brazil	280	15,000	54
	Peru	13	1,200	92
Zinc	Peru	1.4	21	15
	Mexico	0.69	14	20
Bauxite	Brazil	31	2,700	87
	Jamaica	6	2,000	333
Manganese	Mexico	0.22	5	23
	Brazil	0.62	270	435
Nickel	Brazil	0.089	16	180
	Colombia	0.041	0.364	9

Table 2 - 2023 production and reserves in million tons for each ore and country. The metric of remaining years of exploitation is calculated based on the ratio between production in 2023 and reserves.

Source: (USGS, 2024; South32, 2023).

Although LAC has the largest lithium reserves in the world, the global leader in lithium production is Australia, whose reserves are in rock formations, with a higher cost of extraction. Given that lithium demand may increase up to 40 times (Sanin et al., 2023), lithium production in LAC should increase considerably. In recent years SQM, a private Chilean company, has been the largest lithium producer in the world (Sanin et al., 2023), and in 2023, Chile published its National Lithium Strategy (ENL), through which it seeks, among other milestones, to increase lithium exploitation in the country by incorporating Codelco, the state mining company that has so far focused on copper, as a lithium producer in the Salar de Atacama - where both SQM and Albemarle, a US company, operate - and to give concessions to private companies in other salt flats with high lithium potential. Meanwhile, in Argentina there are 38 lithium projects, with three of them in production and five under construction (ArgentinaGob, 2024). Bolivia - which has the world's largest lithium resources (USGS, 2024) - has begun pilot lithium extraction plans in the Salar de Uyuni. Brazil extracts lithium from its Grota do Cirilo rock deposit. Mexico has significant lithium resources of sedimentary volcanic origin in the Sonora valley, which are anticipated to be exploited in the near future (Bacanora Lithium, 2024). Finally, the process of lithium extraction by solar evaporation in ponds has physical and temporal limitations to accelerate production levels, taking between 18-24 months to convert brine to lithium carbonate (Sanin et al., 2023). Emerging technologies such as direct lithium extraction (DLE) have the advantage over the current evaporation pool method of reducing production times by being faster, capturing a higher percentage of the lithium contained in the brine, and reducing environmental impacts such as excessive water use by allowing brine injection into the salar (Sanin et al., 2023). The challenges to be overcome by DLE are the higher investment and extraction costs, the need for fresh water in the process, and the requirement to adapt to the chemical characteristics of each salar (Sanin et al., 2023).

The loss of mineral resource quality and water scarcity creates significant challenges to maintain or expand current extraction levels.

A case in point is copper mining in Chile and Peru, where mines with higher grades have been depleted, and there is a water shortage in the northern mining area of Chile, which makes it difficult to maintain current extraction levels. LAC can invest in more efficient extraction technologies that use less water resources, in the exploration of new resources with a higher degree of concentration, or in technologies to increase water resources, such as desalination plants.



Brazil has a diversity of mineral resources required for the energy transition and can increase its exploitation capacity. Brazil has considerable mineral reserves of lithium, graphite, rare earths, iron, bauxite, manganese and nickel (see Figure 2). Of these minerals, Brazil extracts at a rate of more than 1% annual exploitation, or 50 years of depletion, only lithium (1.25%), iron (1.85%) and bauxite (1.15%) (see Table 2). For the other minerals the level of annual exploitation is very low relative to the level of known reserves, being 0.1% for graphite, 0.0004% for rare earths, 0.23% for manganese and 0.56% for nickel. Brazil must move towards a strategy of extraction and refining of these critical minerals to take advantage of the opportunity to supply the new technologies of global decarbonization.

Social license for mining operations

An important challenge for the extraction of raw materials is the social license to operate, which helps to ensure a responsible long-term supply and improve the perception of mining. Mining for energy transition has important economic and decarbonization benefits, but mineral extraction also generates significant and diverse environmental and social impacts (IDB, 2022). The intangible social approval permission that communities give to mining projects is called social license (Balza et al., 2021). This social license has components of governance, procedural justice, distributive justice and nationalism in the extraction of natural resources (Balza et al., 2021).

It is essential that companies and legislation promote a social license for mining, which is necessary to operate and attract greater investment to the region (IDB, 2022). For mineral extraction to be resilient and reliable, it must be done in a way that protects both communities and the environment, and there must be an active link between mining companies and local communities (IEA, 2023b).

Mining companies often operate with more stringent socio-environmental standards than those required by national legislation, in order to generate trust in their local communities and thus be able to operate efficiently (Rojas-Hayes et al., 2023). A comparative analysis between international standards - often adopted by mining companies - and national regulations in LAC revealed areas for improvement where regulations are less demanding (Rojas-Hayes et al., 2023). Examples of areas for improvement are in governance schemes through greater community participation; strengthening regulations on tailings, mine closure or environmental liabilities; or creating policies to generate greater dialogue and advance gender equity in the sector (Rojas-Hayes et al., 2023).

Governance and long-term certainties

Another important challenge is the governance of each country with respect to its natural resources and their responsible exploitation. The added value of the mineral resource can also be appropriated by companies without adequate regulation in terms of royalties or extraction taxes. Current challenges in the governance of mineral extraction are (IDB, 2020):

- Lack of a shared vision on the role of the mining sector in the long term.
- Guarantees of the capture and distribution of resources generated by mining.
- Promotion of gender equality.

- Strengthening occupational safety and health conditions.
- · Biodiversity conservation and water security.
- · Climate change and carbon footprint.
- Modernization of environmental institutions.
- · Transparency of information.



Adequate management of the mineral resource and a strong and transparent institutional framework are key to addressing these issues. Adequate governance should balance the capture of benefits for the country with a more efficient mining development, together with the mitigation of associated environmental impacts.

The installation of new mining projects requires high initial capital and long-term guarantees for their operation. Countries must provide sufficient long-term guarantees for the private sector to find it attractive to invest in capital-intensive, high-commitment, low-reversibility projects such as mining operations. To be globally competitive, mineral extraction requires access to cheap energy, which implies additional investments in power generation and transmission infrastructure (IGF, 2021). The development of renewable energies, such as solar and wind, is a goal of LAC's energy transition that would bring benefits towards lower cost mining with a lower carbon footprint.

2.3 Recommendations

LAC must take advantage of the window of opportunity and its concentration of critical mineral reserves to increase its production levels, protecting the environment and local communities, fostering regional cooperation, training advanced human capital and promoting investments through long-term institutional certainty.



Protecting local communities and the environment

Mining companies must maintain their leadership in ESG (Environmental, Social and Governance) standards (IDB, 2022). These standards contribute to obtain the social license to operate, reduce the risks of stoppage of activities due to environmental or social problems and promote investment by economic groups that demand these standards (IDB, 2022). Mineral extraction with adequate management of environmental issues and responsibility towards local communities increases the certainty of mining operations in the long term (IEA, 2023b).

- At the company level, there are several actions that can be taken (IDB, 2022), such as increased dialogue with local communities, investing in local development through collaborative projects and employing local labor, working together with indigenous communities by identifying and respecting their rights, developing local infrastructure, and fostering economies that persist post-closure of mining operations.
- At the regulatory level, the demands of national regulations should be brought closer to the requirements of international standards, especially in the areas of tailings, mine closure and environmental liabilities; comprehensive citizen participation; gender diversity and opportunities; and transparency access to information in a simple and direct manner to local governments and communities (Rojas-Hayes et al., 2023).

LAC can increase its participation in the extraction of critical materials by updating regulatory standards for mineral exploitation and environmental standards (IDB, 2022). LAC should take advantage of the window of opportunity by respecting the environment and local communities (Sanin et al., 2023). To improve the governance of mineral resources, public-private coordination should be strengthened (Sanin et al., 2023), concessions should be increased, and strategic plans and programs should be developed, considering incentives for the most advanced industry in the value

chain (Sanin et al., 2023). Strengthening governance and institutions for economic, legal and social development promotes greater social license for mining, which decreases the number of mining-related conflicts and provides certainty in long-term operation (Balza et al., 2021).

The International Energy Agency (IEA) provides five recommendations for governments to ensure sustainable mineral extraction (IEA, 2023b), which apply especially to the case of LAC:

- O1 Provide a robust regulatory framework that protects communities and promotes sustainable mining, along with adequate oversight.
- O2 Direct public spending to encourage good practices in mining. Through public spending, such as tenders, public works, or concessions, governments can incentivize more sustainable companies and technologies.
- O3 Generate standardized data collection systems to compare companies with each other and promote adequate and efficient development.

- Promote transparency in mineral extraction, generating public reports, communicating risks and mitigation measures.
- O5 Support the development of voluntary sustainability standards as a complementary role to local legislation.

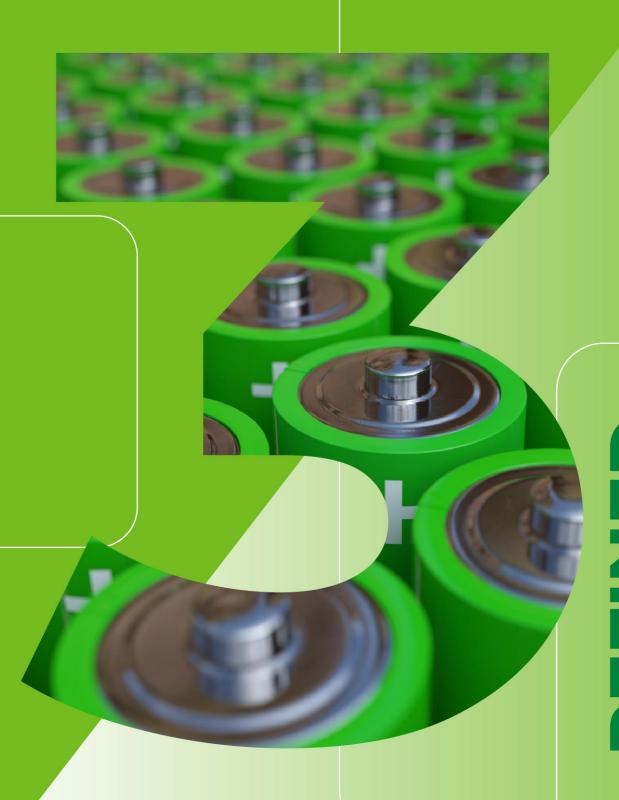
Promote greater regional cooperation in technology and human capital development

Regional cooperation in technology and human capital is key to boosting mining development in LAC. Mining companies in LAC can mutually benefit by sharing investments in technological developments for more efficient extraction. For example, copper extraction and refining require high industrial technologies, which can be perfected through collaboration between copper mining countries, such as Chile and Peru. Direct lithium extraction is another emerging technology that will potentially allow the region to lead the world in production by enabling faster and more efficient extraction of lithium from brine, with lower environmental impacts, but at higher extraction costs (Sanin et al., 2023; Goldman Sachs, 2023). Argentina, Bolivia and Chile could potentially benefit from this technology, so joint efforts - such as resources for research and pilot schemes - can be coordinated to implement it in the region.

Providing long-term institutional certainty

LAC must provide long-term institutional certainties to attract investment for large mining projects. Mining projects require large upfront investments and have very long useful lives - greater than 30 years, given the inability to extract all the ore immediately (Vikström, 2013) - so companies require long-term certainty about the amount of reserves, demand for minerals and permits to extract them. The current global market situation provides two major certainties for investors: LAC has significant mineral reserves and demand for minerals will grow exponentially given global decarbonization plans. Governments can complement this opportunity and encourage investment by providing greater institutional certainty, setting consistent regulations, adequate environmental permitting timelines, and clear rules regarding quotas and long-term extraction permits. For the above, mineral resource governance laws are fundamental, as well as the history of mining extraction in each country. This does not imply removing tax variables in mining, but rather ensuring stable and predictable rules over the medium and long term. Likewise, this government support can be under the minimum requirement that mining companies commit to developing local communities, generating employment, training workers and respecting environmental institutions.

On specific governance challenges, LAC governments can move forward with several specific actions (IDB, 2020). They can convene multilateral dialogues among the various stakeholders in the mining industry to generate a common vision on the long-term role of mining for LAC. They can also create stabilization funds and promote efficient and effective public spending from the resources generated by mining. Another action is to adopt practices to advance gender equity in the industry; and to advance more rigorous occupational safety and health standards. They can also promote sustainable projects with low impact on biodiversity and water resources in the area; and promote the reduction of carbon emissions in the mining industry, with concrete and progressive emission reduction goals towards carbon neutrality. Finally, they can review and improve environmental regulations and oversight processes; and create simple, direct and updated information platforms to strengthen effective communication with governments and communities.



REFINED

3.1 Opportunities

Leveraging mineral extraction progress with refining industry

LAC can use its comparative advantages in mineral reserves and raw material extraction to leverage further growth in the refined ore industry by encouraging nearshoring, or the joint production of both stages of the value chain in the same region. Exporting refined ore increases the value added of the mining industry and the economic benefits for each country. Several studies have shown that new refinery installation projects have a high profitability, for example 12.9% for copper (CESCO, 2020), derived from higher sales revenues and lower ore transportation costs. The refined material can also be used as a main input for other industries in the value chain, such as the manufacture of solar panels, wind turbines or lithium batteries (see Chapter 4 - Manufacturing for more details). A joint strategy in expanding feedstock extraction and refining would allow for greater economic development in LAC.

ALC has experience in refining minerals of worldwide use, such as copper in Chile. Chile currently has 4 copper smelters - Caletones, Altonorte, Paipote and Chagres - and two smelter-refineries - Chuquicamata and Potrerillos (CESCO, 2020), after Ventanas closed operations in 2023. Other countries with copper extraction or reserves, such as Mexico or Peru, are not currently involved in refining, so they can incorporate using their mineral resources directly.

High concentration reserves facilitate mineral refinement

The geological occurrence at high concentrations of certain minerals, such as lithium, provides comparative advantages for direct refining of the mineral. Lithium from brines facilitates the production of lithium carbonate or lithium hydroxide, ready to be used in the manufacture of cathodes for electric batteries (Sanin et al., 2023).

Brazil can produce metallurgical silicon, a fundamental component in the manufacture of solar panels. Brazil has the following opportunities to enter this market: an increase in demand for metallurgical silicon is expected, it has the raw materials for its production - such as quartz, coal and wood - and it has a low cost of electricity, mainly from hydroelectric sources (Solar Cluster, 2015). Brazil has deposits with significant reserves of high-quality quartz, necessary for metallurgical silicon, in the states of Minas Gerais, Goiás, Bahia, Espírito Santo and Pará (Solar Cluster, 2015). Notably, Brazil also has the capacity to expand into more advanced stages of the value chain, such as in the manufacture of poly silicon, ingots, solar cells, and solar panels.

Brazil can participate in the refining of natural graphite, given its occurrence in high grades, to be used as an anode in lithium batteries (Ramji and Dayemo, 2024). Natural graphite is comparatively cheaper to produce than synthetic graphite but has lower performance in its use in lithium batteries due to higher impurities (Ramji and Dayemo, 2024). Brazil has reserves of high-grade natural graphite, which is an opportunity to increase its refining capacity and sell it at a higher value.

LAC has strategic alliances with large markets

Recent global industrial policies with a focus on critical minerals such as the Inflation Reduction Act (IRA) in the United States (IRS, 2022) or the Carbon Border Adjustment Mechanism (CBAM) in Europe (EU, 2024), present an opportunity to insert LAC as a reliable supplier of refined minerals to the world. The IRA provides incentives for the EV industry in the United States if 80% of the value of its critical minerals comes from domestic sources or countries with free trade alliances (Trost and Dunn, 2023). LAC countries with a free trade agreement with the United States are Chile, Colombia, Mexico and Peru; and minerals considered by the IRA existing in LAC are aluminum, graphite, lithium, manganese and nickel (USTR, 2024). Argentina and Brazil have significant reserves of critical minerals (Figure 1), which is a benefit in advancing bilateral relations with the US. The IRA brings opportunities for LAC countries with reserves and treaties with the US to insert themselves into its value chain for new decarbonization technologies. Europe's CBAM includes a carbon footprint tax on goods imported into the EU, which could include lithium battery EVs, solar panels and wind turbines. LAC can produce mineral products with a low carbon footprint - given the high quality of its mineral resources and the availability of low-carbon energy, such as solar, wind or hydroelectric - which would give it a comparative advantage over refining minerals with a higher carbon footprint, such as in China. Concrete examples of opportunities in mineral refining are the extraction of lithium in brine, with its lower carbon footprint vis-a-vis lithium from other formations (Khakmardan et al., 2023); and the supply of raw material or components derived from Brazil due to its high renewable energy matrix with lower cost and carbon footprint (Ember, 2023; GlobalPetrolPrices, 2023).

3.2 Challenges

China's dominant position in mineral refining

China, through its industrial strategy, has the largest share in mineral refining (IEA, 2024), despite not dominating mineral extraction. For example, Chile dominates copper extraction (~25% of world share) but not processing (~10%), and for lithium it extracts and processes about 25% of world production (IEA, 2024; USGS, 2024). Peru participates in copper extraction, but not in its refining, missing an opportunity for greater added value. Brazil, despite having 12% of the world's nickel reserves, processes 2.5% of the world's demand for refined nickel. China's dominance in this stage of the value chain is explained by the following comparative advantages (Sanin et al., 2023): high local demand for EVs and solar panels, low energy and labor costs, economies of scale in production and technological availability.



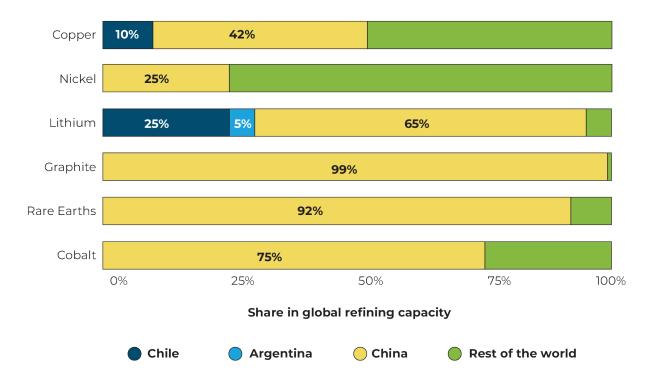


Figure 3 - Global mineral refining capacity, LAC countries indicated. Source: (IEA, 2024).

Volatility of mineral prices and loss of resource quality

Price volatility in metallic minerals can force refinery closures in the short term. For example, the Sao Miguel Paulista nickel refinery, which produced class 1 nickel suitable for conversion to cathode, closed in 2016 due to a decline in the price of nickel (Sanin et al., 2023). A refinery's industrial operation can protect itself financially against price changes through financial support, future contracts or long-term contracts, such as with suppliers of lithium battery factories. Governments can support the industry in commercial relationships and securing long-term demand contracts.

In recent years, LAC has lost its leadership in the world refined copper market, mainly due to the loss of grade in its mineral deposits and the emergence of smelters in China, which, through significant subsidies, have managed to develop new technologies to reduce costs (CESCO, 2020). Other limiting factors in the extraction of high-quality copper are physical barriers in the deposits, whose vertical structure prevents increasing exploitation rates, and greater environmental and social requirements (CESCO, 2020). This requires subsidies for the development of more efficient extraction and refining technologies (such as DLE for lithium), exploration of higher-grade mineral resources, and in the utilization of valuable minerals in mine tailings - such as cobalt and rare earths in copper mining tailings (Kottohoff, 2020). Copper smelters in Chile can operate at profitable margins, have a lower carbon footprint than competitors in China (CESCO, 2020), and would benefit from state subsidies for development of more cost-efficient refining technologies.

LAC should invest in more efficient and sustainable mineral extraction and refining technologies. For example, emerging direct lithium extraction technology could be a competitive advantage for LAC to increase its production of lithium carbonate from brines. China dominates lithium refining mainly using lithium oxide from Australian rock deposits as an input, as brine deposits, present in LAC, have physical limitations on the maximum lithium extraction rate (Sanin et al., 2023). Through new technologies, such as DLE, ALC can be more efficient in lithium extraction and with less environmental impact, and increase its lithium carbonate production levels to 99%, a direct use input for battery cathode manufacturing (Sanin et al., 2023).



High initial capital



Refining silicon metal for solar panels requires high initial capital expenditure, skilled labor, transportation logistics and supply of multiple materials (IDB, 2023). Brazil, which has significant reserves of high-quality silicon (quartz), can find appropriate ways to overcome these challenges and produce silicon metal. For example, regional cooperation in LAC would allow Brazil to obtain other raw materials, such as coal and wood, required in the process. Access to cheaper financing can support the installation of new refining plants for silicon metal, and the development of new, lower-cost renewable energies would increase refining cost competitiveness.

3.3 Recommendations

By increasing mineral production - given its high reserves and low extraction costs - LAC can advance the refining industry and thus leverage its comparative advantages and address its weaknesses relative to other refining markets. LAC should provide incentives to maintain the refining industry in the region.



To take advantage of the window of opportunity and advantage in mineral extraction

Given the growth in global demand for critical minerals, LAC can expand mineral refining production without the need to compete with existing refineries in China. Future demand for critical minerals presents a unique opportunity to open up mineral refining projects without the need to compete with existing refineries. LAC must leverage its comparative advantages, such as having mineral reserves directly available and having major world powers as commercial allies, while at the same time closing the gap with China's competitive advantages in local demand, low energy and labor costs, economies of scale and technological availability. In this regard, the region can promote mineral refining projects through:

- O1 Securing demand for refining materials in LAC given future local demand for solar panels, wind turbines and lithium batteries (see Market chapter).
- O2 Take advantage of low energy costs in certain regions, such as hydroelectric zones in Peru or Brazil, to install competitive refining industries. In electricity systems with a low carbon footprint, LAC may have a comparative advantage in producing refined minerals with a lower climate impact.
- Take advantage of the skilled labor force in the region and encourage specialization in these technological areas through increased training and technical education.
- O4 Prioritize the exploitation of highgrade ore to drive low-cost refining within the region.

Incentivizing the local refining industry

LAC can provide incentives for the refining industry, if they are carried out with respect for local communities and the environment. Since mineral refining provides higher value added, fiscal support or forward price agreements can be provided as an incentive to open new refining plants. LAC can generate important synergies with the mineral refining industry - such as securing future demand - if it succeeds in developing a major manufacturing industry for solar panels, wind turbines and lithium batteries (see Chapter 4). This synergy should be exploited through regional cooperation and commercial alliances between LAC countries, given that the reserves of each mineral tend to be concentrated in certain countries, such as copper in Chile, lithium in Argentina, Bolivia, Chile and graphite, nickel and silicon in Brazil (see Figure 2). LAC can take advantage of the opportunities provided by recent economic policies in the US and Europe, taking advantage of the mechanisms to insert itself into the emerging value chains of these regions.



Latin America and the Caribbean is strategically positioned to lead in the manufacture of equipment for the global energy transition, taking advantage of its abundant natural resources, its skilled labor force, its infrastructure and international trade positioning, and the growing global demand for clean technologies. Local manufacturing of green technologies and their components, such as lithium batteries, solar panels and wind turbines, brings great opportunities to the region. Although it is important to keep in mind that local manufacturing may have a higher initial cost compared to imports, this initial price premium is offset by long-term benefits. In this context, it is not a matter of directly replacing imported components, such as solar cells, with more expensive local versions, but of assembling these products locally using imported components. While this approach may temporarily slow down the energy transition due to the higher costs of locally assembled products, it is a strategic decision that prioritizes long-term benefits such as local economic growth, job creation and strengthening of regional industry. It contributes to the region's energy sovereignty by reducing the strengthening of regional supply chains. In addition, over time, the establishment of regional and nearby markets can lower transportation costs, further offsetting some of the initial price increases.

For the private sector, the local manufacture of these technologies can represent a trigger for a virtuous cycle of growth and prosperous development since, through their implementation, companies will be able to significantly reduce their energy consumption and GHG emissions and, consequently, reduce their operating costs and environmental impact. This will not only help to comply with strict environmental regulations and attract environmentally conscious consumers, but also increases the resilience of the supply chain to fluctuations in international fossil fuel prices, thus optimizing production to be cleaner and less dependent on polluting energies.

It is important to highlight that the most efficient measure to boost the regional development of this industry - as well as to improve the technological capabilities of LAC countries and position themselves as leaders in the renewable energy market - is international collaboration and regional integration, to make the most of the strengths and resources of each country (IDB, 2023).



However, participating in this global market presents several challenges. The high initial investment required to increase manufacturing capacity, combined with reliance on imports of critical materials, exposes the region to vulnerabilities in the global supply chain. In addition, competition with established global manufacturers poses a significant obstacle to gaining a larger market share. Therefore, it is crucial that LAC not only invest in expanding its manufacturing capacity, but also in developing integration strategies to combine resources and industrial capabilities to help mitigate these risks and take advantage of emerging opportunities in the renewable energy sector.

4.1 Opportunities

Lithium battery production

According to IDB estimates, by 2035, the demand for batteries for energy storage and EVs in LAC will increase to 174 GW, a 500% increase over 2023. To put this figure in perspective, LAC demand will represent 7% of the estimated global demand, which will be 2,519 GW for the same year (IDB, 2023).

LAC has a significant opportunity to increase its participation in the high-value segments of the lithium battery supply chain, a critical component for the global energy transition. This opportunity is mainly due to, as described above, the abundance of lithium reserves in countries such as Chile, Argentina or Bolivia, providing a solid base for the development of this industry.

The lithium value chain process involves several stages, from the extraction and processing of raw materials to the manufacture of advanced components and the final assembly of batteries. LAC can improve its position in this chain and reduce dependence on other markets outside the region by investing in higher value-added manufacturing processes. For example, by taking advantage of the growing demand for lithium batteries for EVs to develop regional capacities to produce precursors and cathodes, essential elements in their manufacture.

A potential regional cooperation scenario for lithium battery manufacturing could be based on recent investments in production capacity in Chile and Mexico, as well as the availability of critical mineral deposits in Argentina. Each country would focus its efforts on different stages of the value chain. On the one hand, taking advantage of the country's extensive lithium reserves, Chile has implemented a strategy that includes significant investments in the production of precursors and cathodes. On the other hand, taking advantage of its industrial capacity, manufacturing experience and strategic position to export to North American markets, Mexico has begun to invest in the installation of battery assembly plants (IDB, 2023). These investments in specific production capacities not only strengthen their own industries, but could lead to regional collaborations, where each country specializes in different segments of the value chain as shown in Figure 4.

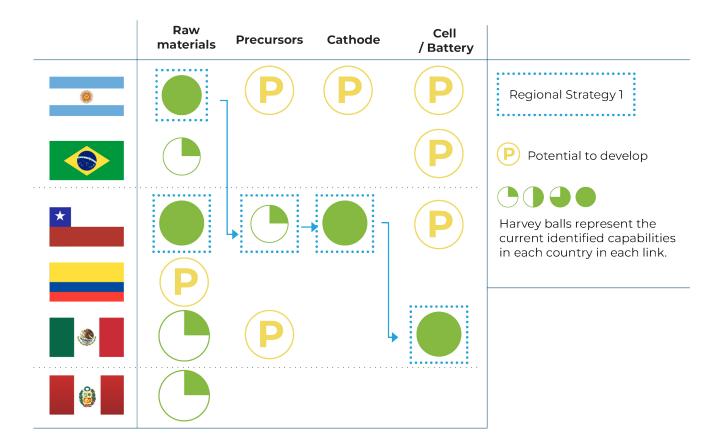


Figure 4 - Regional cooperation scenarios for battery production. Source: IDB, 2023.

This regional integration approach has the potential to promote cross-border collaboration, optimize existing resources and manufacturing capabilities, and create a more resilient and globally competitive industrial ecosystem. All this to effectively respond to and take advantage of the growing demand for EV batteries and renewable energy storage systems.

Production of components for solar photovoltaic systems

In LAC, solar PV capacity is expected to increase significantly, almost tripling by 2030 and reaching 227 GW by 2035. This growth is expected to remain constant, with an annual growth rate of 13.7%, representing an increase of between 7 and 20 GW of new capacity each year (IDB, 2023).

To capitalize on this growth, the main opportunity for the region lies in participating in the entire value chain. Currently, imported input costs represent 36% of total production costs in the sector in LAC, including subcomponents such as already manufactured solar cells (IDB, 2023). To reduce the impact of these costs and increase competitiveness, the region could increase the production of subcomponents. This would not only decrease dependence on expensive imported materials, but also promote self-sufficiency and reduce exposure to supply chain disruptions. Facilitating efficient trade within the region would further optimize the costs associated with imported materials, thereby improving the overall competitiveness of the solar industry. In addition, sourcing raw materials from local suppliers with lower transportation costs would significantly reduce transportation costs, contributing to regional economic growth.

As in the case of batteries, two strategies are proposed for the creation of regional supply networks to strengthen the solar industry in LAC, see Figure 1. Figure 5based on the analysis presented in IDB, 2023.

On the one hand, taking advantage of Brazil's production capacity, the company plans to strengthen its solar panel production by creating synergies with neighboring countries such as Argentina and Chile to ensure the supply of essential raw materials such as silicon. This strategy includes the formation of strategic alliances and the reduction of tariffs on raw materials, fostering greater regional economic integration. This approach not only boosts the solar industry in Brazil, but also promotes more efficient use of regional resources.

On the other hand, Mexico also has a large manufacturing capacity and access to North American markets, so it is proposed to integrate the production of silicon with the help of countries such as Colombia and Peru, and then process this silicon in Mexico for its incorporation into the solar panel value chain. This initiative includes the development of the polysilicon industry in Mexico, with the aim of strengthening local production and reducing dependence on imports.

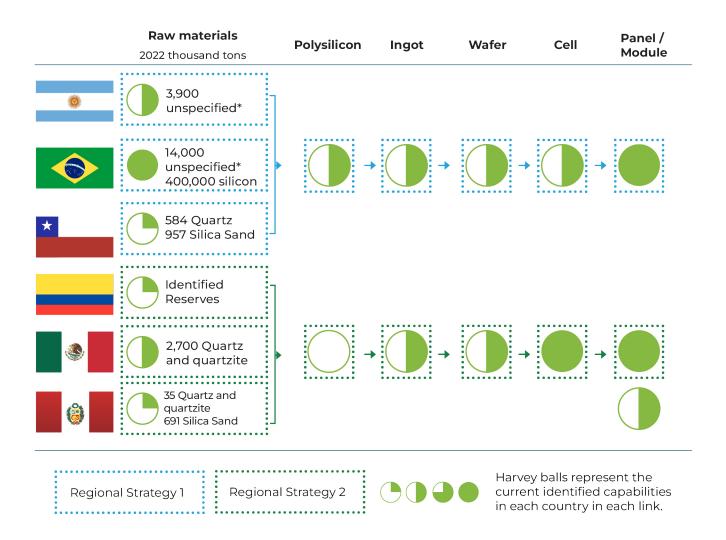


Figure 5 - Cooperation scenarios for solar panel production. Source: (IDB, 2023).

The proposed strategies seek to establish regional self-sufficiency in key components for the solar industry and increase competitiveness vis-à-vis foreign products. In addition, technology transfer and knowledge sharing between international and local manufacturers is expected to improve manufacturing capabilities in the region, positioning Latin America as a key player in the global renewable energy market.

Production of Wind Turbines

Currently, the region has ample availability of minerals and materials necessary to produce equipment and components for wind power generation. These diverse resources include, for example, steel for towers, copper for cabling, glass and carbon fibers for blades, and concrete for foundations. A critical exception is the scarce production of rare earths, which are essential for the manufacture of different technologies, such as the magnets used in certain types of wind turbines and electric vehicle motors. Brazil is the only country in the region that produces rare earths in substantial quantities, accounting for 90% of global niobium reserves, and is responsible for approximately 86% of global production (USGS, 2024).

The three countries with the most significant participation in the value chain of components for wind energy production are Argentina, Brazil and Mexico. They play active and complementary roles in the wind energy value chain in Latin America. Argentina is expanding its wind turbine component manufacturing capacity, attracting investment and specializing in specific aspects of production (IDB, 2023). Brazil, with a well-established wind market and efficient project development processes, supplies wind power to its domestic electricity demand and benefits from low installation costs. Mexico, on the other hand, takes advantage of its geographical position to export wind subcomponents to the United States and is working to strengthen its regional integration by reducing tariffs and improving logistics infrastructure.

According to estimates in IDB, 2023, LAC currently has an installed wind energy capacity of 45 GW and is expected to increase 250% by 2035, representing an annual growth rate of 4 to 8 GW of capacity to reach 114 GW.

To respond to this accelerated growth, it is proposed that Argentina, Brazil and Mexico strengthen their regional cooperation to optimize the manufacture of wind power equipment. Under this scheme, Argentina and Brazil would focus efforts on strengthening their wind turbine production capabilities, integrating regional raw materials and increasing the production of rare earths essential to produce turbines. Mexico, on the other hand, would focus on securing the supply of essential materials and then boosting its turbine production.

As shown in Figure 6 As Figure 6 shows, each of these countries has a strategic position within the wind energy value chain, so that joint efforts could not only expand production efficiency and manufacturing capacity, but also consolidate the region as a leading competitor in the global wind energy market, jointly leveraging the advantages of its industrial infrastructure and natural resources.

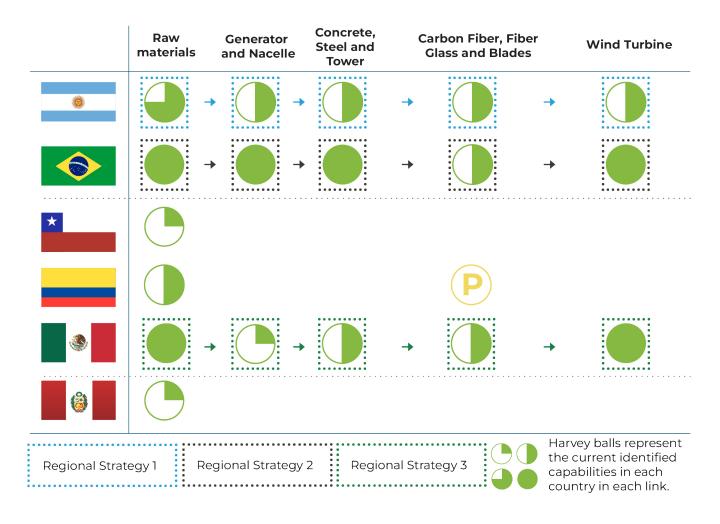
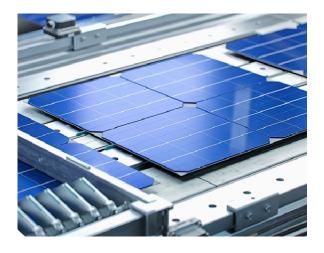


Figure 6 - Cooperation scenarios for wind turbine production. Source: (IDB, 2023).

4.2 Challenges

Insufficient capacity in high value-added processes



The lack of capacity in high value-added processes in the value chains of technologies such as silicon for solar components and lithium for batteries in LAC has significant implications for the region's industrial and technological development. This concentration on the production of raw materials and final assembly, without investing in intermediate processes, limits the region's capacity to create higher value-added products. Such a situation not only reduces potential profit margins for local industry, but also perpetuates dependence on advanced technologies and processes from more industrialized countries, weakening regional technological autonomy.

In addition, this deficiency in the value chain hampers the region's ability to respond to global supply disruptions, making the industry vulnerable to fluctuations in the availability and price of imported materials. This can have destabilizing effects on local production, increasing production costs and limiting the competitiveness of final products in the global market.

Lack of regional integration

The lack of regional integration in LAC profoundly affects the value chains of wind, solar and energy storage technologies, limiting the region's economic and technological development. This prevents countries from taking advantage of economies of scale, leading to reduced efficiency and higher production costs, as each country may end up replicating infrastructure and capabilities that could be more effectively developed and leveraged at the regional level. In addition, trade barriers such as tariffs and other regulatory obstacles further complicate the import and export of critical materials and technological components, restricting the flow of innovations and reducing the overall competitiveness of the region's clean technology industry.

These challenges not only limit the expansion of the renewable energy industry, but also hinder the region's ability to respond nimbly to market demands and global technological changes. The lack of regional integration may leave Latin America and the Caribbean at a disadvantage in the global race for energy transition to cleaner and more sustainable sources, holding back the potential for economic growth and job creation in technologically advanced sectors.

Lack of investment

The lack of investment in advanced technologies in LAC poses significant challenges for the development and expansion of the infrastructure needed to manufacture green technologies. Difficulty in accessing affordable financing limits not only the creation of new production facilities, but also the upgrading and expansion of existing productive capacities. This slows technological development in the region, preventing LAC from taking full advantage of its potential in fast-growing sectors such as renewable energy and battery technology.

In addition, the substantial upfront investment required to establish advanced technology manufacturing plants may be prohibitive for many potential investors, slowing innovation and industrial expansion. In an increasingly competitive global marketplace, this lack of investment could relegate the region to a marginal role, unable to compete with more developed markets that invest significantly in modernization and production efficiency.

Risk in the supply chains of critical materials not available in LAC

Shortages of key materials, such as the rare earth elements used in the manufacture of certain types of wind turbines or the cobalt present in the lithium batteries of chemistries such as NMC (nickel, manganese, cobalt), highlight the need to strengthen global supply chains in the region. This deficiency can lead to disruptions in production and affect the stability and reliability of supply chains. Excessive dependence on a few trading partners as suppliers of these critical materials

exposes the industry to risks arising from fluctuations in global markets, as well as political and economic tensions that could alter availability and prices. This underscores the importance of building relationships with multiple suppliers and deepening existing business relationships.

In the context of renewable energy, where continuity and efficiency of production are vital, these challenges could hinder the region's efforts to increase its sustainable energy capacity.

Established global competence

Established global competition in renewable energy technologies presents several challenges for LAC producers. Manufacturers in the region face the tough task of competing with well-established international producers, such as China, Europe or the US, which have advantages in terms of economies of scale or access to advanced technologies and have well-developed supply chains. This can significantly hinder the ability of LAC producers to gain market share and expand into new markets, thus limiting their growth.

In addition, intense competition from established markets can put pressure on local producers to reduce costs, which can often result in compromises in quality or investment in innovation. The lack of a strong research and development base within the region can leave these producers vulnerable to falling behind in terms of the technological evolution needed to remain competitive in an ever-changing global marketplace.



4.3 Recommendations

The following are a series of recommendations to address the challenges identified in the previous section and to take advantage of the opportunities to facilitate the development and strengthening of regional manufacturing of equipment and components for the energy transition.



Regional actions for batteries

To strengthen and boost lithium battery manufacturing in LAC, it is critical to adopt a near-term strategy that leverages the countries' current capabilities while preparing for a transition to a comprehensive regional value chain. This will enable the region to respond effectively to the accelerated growth in demand for lithium batteries.

It would be strategic to **invest in the manufacture of complete batteries and their components, taking advantage of the availability of regional raw materials and developing battery supply chain diversification programs.** The region can take advantage of Mexico's regional mineral extraction and low labor costs, as well as existing manufacturing capabilities to expand lithium refining in countries such as Chile and Argentina. For example, it can seek to promote the installation of cathode production plants in Chile, with commercial alliances for Mexico's EV industry (IDB, 2023).

In addition, it is necessary to **design new regional financing schemes that encourage investments in local value chains**, such as preferential loans for battery manufacturing companies, special investments in the production of precursors and cathodes, or tax incentives for machinery used in lithium processing.

Regional actions for wind energy

To boost the development of wind energy in LAC, it is crucial to implement regional actions that strengthen and increase regional participation along the entire value chain. For example, reducing existing intra-regional trade barriers would facilitate the development of a value chain that consolidates the strengths of the regional wind industry, taking advantage of existing production capacities in countries such as Argentina, Brazil and Mexico, as well as assembly facilities in Brazil.

On the other hand, cooperation is also important for the development of regional logistics infrastructure for the transportation of the huge wind energy related components. This is a

critical consideration for the export of wind turbines within the region as the size and weight of the towers and blades present oversized cargo challenges that could hinder the efficient supply of this infrastructure.

Finally, Argentina, Brazil and Mexico can expand their manufacturing industries through partnerships with other LAC countries for the extraction of key raw materials, such as copper, zinc, manganese, iron and rare earths. These actions will help position LAC as a major player in the wind energy sector and promote sustainable development throughout the region.

Regional actions for solar energy

To promote the development of solar energy in LAC, it is essential to implement regional actions to promote the diversification and strengthening of the solar supply chain in the region.

An important opportunity is to develop a solar supply chain diversification program, taking advantage of each country's strengths and opportunities, capitalizing on the projected increase in solar energy demand, relying on LAC countries for the extraction of key raw materials such as silicon from Brazil, copper from Chile and Peru, and zinc from Mexico and Peru.

On the other hand, similar to the case of the previous technologies, there is a great opportunity to design new regional financing schemes that encourage investments in local value chains. For example, preferential loans and tax incentives. Similarly, there is a need to reduce tariffs and non-tariff barriers on goods and services associated with solar energy production, to facilitate trade of raw materials and key minerals from producing countries to countries with processing capabilities, or to facilitate the transfer of products for final assembly in Brazil and Mexico and from there to their export destination.

Finally, working in collaboration with regional ministries of energy and mines, as well as academic and research institutions, is paramount to support research and development activities with regional resources, promoting increased productivity and quality of solar products in the region. In addition, this could strengthen technology transfer, increase personnel training and promote the development of technologies adapted to the needs of the LAC market.



MARK

As highlighted in the previous chapter, the global market for energy transition technologies is experiencing accelerated growth, driven by a variety of objectives and strategies at both the national and international levels to address climate change. On the one hand, by 2030, electricity demand in the region is estimated to double compared to the 2015 level with an 18.9% share of solar and wind power (Graham et al., 2021), requiring a large amount of storage in the form of lithium batteries. On the other hand, EV adoption is already underway in some markets in the region. In 2021, 25,000 new EVs were registered, doubling 2020 levels (BloombergNEF, 2022) and the market is expected to continue to grow, supported by public sector initiatives and targets in different countries in the region. Some of these initiatives include requiring new cars sold to be electric, replacing urban bus fleets with electric buses, and introducing electric passenger and freight trains.



This rapid evolution not only creates significant opportunities, but also poses unique regional challenges. Leveraging natural, infrastructural and human capital advantages becomes crucial to secure a prominent place in one of the world's most promising global markets.

5.1 Opportunities

Export markets: short-term opportunity for financing regional capacity

LAC has robust production capacity and infrastructure and established trade relationships for the export of energy transition technologies, including solar, wind and energy storage. Export markets: short-term opportunity to finance regional capacity.

LAC has robust productive capacity and infrastructure and established trade relations for the export of energy transition technologies. In particular, the largest economies in the region, such as Argentina, Brazil, Chile, Colombia, Mexico and Peru, already participate in several trade agreements and conventions, such as Mercosur, the Pacific Alliance and the T-MEC. These alliances can support the recommendations made in the previous section (manufacture) by facilitating market integration and the expansion of clean energy exports. Figures 7, 8 y 9 present the cumulative value of LAC export markets for solar panels, lithium batteries, and wind turbines from 2019 to 2023.

Major LAC exporters

		Mexico	Chile	Brazil
Main import destinations	USA Argentina Honduras Guatemala Paraguay Bolivia Peru Ecuador Colombia	80.2% 0.0% 0.0% 0.0% 0.0% 0.0% 0.0% 0.0%	0.5% 3.1% 0.0% 0.0% 1.8% 1.8% 1.9% 0.2% 0.0%	1.1% 0.3% 0.0% 0.0% 0.2% 0.1% 0.0% 0.2% 0.4%
	Uruguay	0.0%	0.0%	1.3%

Total value of exports 2022-23: \$7.6M

Table 3- Value of the main LAC solar panel export markets and their main exporters, 2022-2023. The values of the flows are presented as a percentage of the total value of trade, located at the bottom of the table. Export values reported by exporting countries under HS tariff codes HS 854143: Assemblies in modules or panels of photovoltaic cells are considered. Source: (United Nations Statistics Division 2024).

Major LAC exporters

		Brazil	Mexico	Chile	Argentina
nations	USA	69.2%	21.1%	1.6%	0.6%
Ę.	Germany	1.6%	0.0%	0.0%	0.0%
na	Brazil	0.0%	0.1%	0.0%	0.4%
import desti	Chile	0.4%	0.0%	0.0%	0.2%
	Argentina	0.4%	0.0%	0.0%	0.0%
	Colombia	0.2%	0.1%	0.0%	0.2%
	Peru	0.2%	0.0%	0.3%	0.0%
	Canada	0.0%	0.2%	0.0%	0.0%
	China	0.1%	0.1%	0.0%	0.0%
Main	Mexico	0.1%	0.0%	0.0%	0.1%

Total value of exports 2019-23: \$604.1M

Table 4- Value of the main export markets for wind turbine nacelles, blades and hubs from LAC and their main exporters, 2019-2023. The values of the flows are presented as a percentage of the total value of trade, located at the bottom of the table. Export values reported by exporting countries under Harmonized System tariff codes HS 850231: Industrial wind turbines with electric power generation capacity, and 841290: Parts of driving motors including blades and hubs for wind turbine are considered. Source: (United Nations Statistics Division 2024).

Major LAC exporters

		Mexico	Panama
ט ע	USA	96.4%	0.0%
ort	China	0.6%	0.0%
d iž	Cuba	0.0%	0.5%
<u>.</u> <u>.</u> .	Peru	0.0%	0.2%
ain est	Haiti	0.0%	0.0%
Maj	Argentina	0.0%	0.0%

Total value of exports 2019-23: \$175.1M

Table 5- Value of LAC's main battery export markets and its main exporters, 2019-2023. Flow values are presented as a percentage of total trade value, located at the bottom of the table. Export values reported by exporting countries under HS tariff codes HS 850650: Lithium cells and batteries are considered. Source: (United Nations Statistics Division 2024).

Latin American and Caribbean (LAC) export markets, especially the United States and Europe, are experiencing growing demand for energy transition equipment and components, driven by climate change mitigation goals. In the case of the USA, in 2021 the administration set a national target of 80% of the country's electricity consumption to be produced using renewable sources by 2035. This represents an increase of 380% over 2021 levels, at a rate of about 4.3% per year. For its part, in 2023, the European Commission set a target of 42.5% of the energy used in the EU to come from renewable sources by 2030, representing a 100% increase over 2021 levels, at a rate of around 3.2% per year.

It is worth noting that the USA currently receives 79% of LAC exports of solar panels, 98% of exports of wind turbines and 94% of exports of lithium batteries, representing 5%, 15% and 10%, respectively, of imports of these technologies in that country. On the other hand, while Europe and LAC maintain strong trade relations in many sectors, in the case of the energy transition technologies analyzed, trade with the bloc represents less than 1% of LAC exports for the three technologies.

Access to advanced markets: Financing and bridging the technology gap

As can be seen in Figures 7, 8 and 9 the North American market is by far the largest consumer of the products exported by the region. This is why Mexico's relationship in the Treaty between Mexico, the United States and Canada (T-MEC, per its acronym in Mexico) is a key factor in boosting the green technology industry in LAC, since through this trade agreement the region can access one of the largest and most thriving consumer markets in the world under privileged conditions. This is particularly true since the adoption in the United States of nearshoring, a policy that seeks to strengthen its supply chains by bringing them closer to allied countries. For the T-MEC partners, the results of this strategy materialized in the IRA, which provides various tax incentives for the purchase of clean components and technologies with final assembly in North America, thus boosting regional manufacturing.

The high demand and favorable prices achieved in these regions offer a strategic opportunity to justify the capital investments (CAPEX) needed to adapt and expand regional manufacturing capabilities for high value-added components. By financing technological production capacity in LAC backed by favorable export prospects to developed regions, the transfer of know-how and advanced technology to the region could be facilitated. This could help close the technology gap and improve LAC's innovation capacity in the field of energy transition.

Moreover, given that the adoption of these technologies is expected to advance at a more moderate pace than in advanced economies, the same installed productive capacities, initially financed by high-value exports, could be easily adapted to develop technologies that meet the needs and purchasing power of the population in the region. This could drive the energy transition in LAC, as well as contribute to sustainable development and foster a robust domestic market in the region.

Intra-regional markets: Betting on clean growth in LAC



The markets for renewable energy technologies in LAC, as discussed in the previous chapter, are at an incipient stage, although accelerated growth is projected for the next decade. As the region takes advantage of its abundance of natural resources and develops its industrial infrastructure to strengthen its production, there has been an increase in the integration of these technologies into local markets, reflecting sustained growth and wider acceptance of renewable energies.

Figures 10, 11, and 12 present the cumulative value of imports to LAC of solar panels, lithium batteries and wind turbines from 2019 to 2023. They highlight the large markets of Brazil, Chile, Argentina and Mexico and the large growth potential for the rest of the region.

Regional integration to reduce costs and have greater influence on production

There is great potential for greater regional integration through trade agreements to strengthen energy transition technology industries, leveraging collective resources and markets. Collaboration among countries in the region could lead to greater efficiency and reduced costs for users through the sharing of infrastructure and human capital.

Main exporters to LAC

	China	Singapore	Vietnam	Japan
Brazil	88.5%	0.2%	0.1%	0.1%
Colombia	3.9%	0.0%	0.0%	0.0%
Chile	3.7%	0.0%	0.0%	0.0%
Mexico	1.5%	0.0%	0.0%	0.0%
El Salvador	0.5%	0.0%	0.0%	0.0%
Pere	0.4%	0.0%	0.0%	0.0%
Panama	0.3%	0.0%	0.0%	0.0%
Nicaragua	0.2%	0.0%	0.0%	0.0%
Costa Rica	0.1%	0.0%	0.0%	0.0%
	Colombia Chile Mexico El Salvador Pere Panama Nicaragua	Brazil 88.5% Colombia 3.9% Chile 3.7% Mexico 1.5% El Salvador 0.5% Pere 0.4% Panama 0.3% Nicaragua 0.2%	Brazil 88.5% 0.2% Colombia 3.9% 0.0% Chile 3.7% 0.0% Mexico 1.5% 0.0% El Salvador 0.5% 0.0% Pere 0.4% 0.0% Panama 0.3% 0.0% Nicaragua 0.2% 0.0%	Brazil 88.5% 0.2% 0.1% Colombia 3.9% 0.0% 0.0% Chile 3.7% 0.0% 0.0% Mexico 1.5% 0.0% 0.0% El Salvador 0.5% 0.0% 0.0% Pere 0.4% 0.0% 0.0% Panama 0.3% 0.0% 0.0% Nicaragua 0.2% 0.0% 0.0%

Total value of imports 2022-23: \$8,880M

Table 6- Value of the main LAC solar panel import markets and their main exporters, 2022-2023. The values of the flows are presented as a percentage of the total value of trade, located at the bottom of the table. Import values reported by importing countries under HS tariff codes HS 854143: Assemblies in modules or panels of photovoltaic cells are considered. Source: (United Nations Statistics Division 2024).

Main exporters to LAC

	1	China	Spain	USA	Germany	India	Vietnam	Brazil
i,	Chile	25.6%	4.5%	1.4%	4.3%	2.8%	0.9%	1.1%
Main import destination	Mexico	9.4%	2.5%	4.6%	0.4%	2.1%	0.4%	0.0%
	Brazil	8.1%	2.2%	1.7%	0.6%	0.6%	0.0%	0.0%
	Argentina	10.0%	0.2%	0.7%	0.4%	0.1%	0.0%	0.0%
aii est	Colombia	5.9%	0.0%	0.4%	0.2%	0.2%	0.0%	0.0%
Σΰ	Bolivia	1.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%

Total value of imports to LAC 2019-23: **\$6,236.8 M**

Table 7- Value of the main LAC wind turbine nacelle, blade and hub import markets and their main exporters, 2019-2023. The values of the flows are presented as a percentage of the total value of trade, located at the bottom of the table. Import values reported by importing countries under Harmonized System tariff codes HS 850231: Industrial wind turbines with electric power generation capacity, and 841290: Parts of driving motors including blades and hubs for wind turbine are considered. Source:(United Nations Statistics Division 2024).

Principales exportadores de ALC

r Sc		China	USA	South Korea	Japan	Israel	Indonesia
lain impoi estinatior	Mexico	19.0%	18.9%	13.5%	11.6%	6.9%	5.6%
	Brazil	6.7%	0.9%	0.2%	0.4%	0.1%	1.0%
	Argentina	0.4%	0.4%	0.0%	0.1%	0.0%	0.3%
	Chile	0.8%	0.4%	0.0%	0.1%	0.1%	0.0%
≥ ७	Colombia	0.7%	0.5%	0.0%	0.1%	0.0%	0.0%

Total value of exports 2019-23: **\$1,118.2M**

Table 8- Value of LAC's main battery import markets and its main exporters, 2019-2023. Flow values are presented as a percentage of total trade value, located at the bottom of the table. Import values reported by importing countries under HS tariff codes HS 850650: Lithium cells and batteries are considered. Source: (United Nations Statistics Division 2024).

Leveraging public policies to boost the market

Public policy plays a crucial role in driving and developing the market for renewable energy technologies. By establishing a clear and stable regulatory framework, governments can create an enabling environment for both local and foreign investments in renewable energy. These policies can include tax incentives, subsidies, preferential tariffs for renewable energy generation, and the organization of tenders that guarantee a market for the energy produced. In addition, they can facilitate the development of infrastructure necessary for the expansion of these technologies, such as improvements in the electrical grid and energy storage systems.

On the other hand, clear economic and discursive support from the public sector can promote research and development of new technologies, support education and training of professionals in the sector, foster collaboration between the public and private sectors and reinforce a favorable opinion of consumers.

Strengthening the market to reduce carbon footprint and pollution

By investing in and expanding the use of technologies such as solar, wind, and batteries, the region can decrease its dependence on fossil fuels and, therefore, CO2 emissions and other pollutants. The popularization of these technologies not only helps mitigate climate change by reducing emissions, but also promotes energy security and sustainability. A well-developed renewable energy market can provide clean and affordable energy, which reduces the need to import fossil fuels and strengthens the local economy. Furthermore, by improving energy efficiency and increasing the share of renewables in their energy mix, LAC countries will achieve their climate commitments and targets more easily.

5.2 Challenges

Unequal access to market benefits

In LAC there is significant variability in the level of market development of energy transition technologies among the different countries, as shown in the figures in this chapter. This is due to various factors such as economic stability, government policies, access to financing, or availability of natural and human resources. Some countries, such as Brazil, Chile, and Mexico have made considerable progress in developing their solar and wind energy markets, while others are still in the initial stages.

These inequalities can affect the ability to attract investment, develop infrastructure and limit the capacity to participate in regional cooperation that could facilitate a more efficient distribution of resources and technology.

Risk of a market dominated by international suppliers

The heavy reliance on China and the US as the main suppliers of equipment and components to the region raises concerns about unhealthy market consolidation and potential risks to future growth and sustainability due to possible changes in the trade policies of either country. Especially considering increased trade barriers imposed between the two nations in recent times, potentially resulting in critical supply chain disruptions.

Although technologies produced abroad may offer lower costs and greater availability in the short term, dependence on imports impedes technology transfer and the development of regional capacities to produce these technologies, and in the worst case could even risk energy sovereignty and decarbonization in LAC.

Trade barriers hold back markets

Trade barriers in the region have a significant impact on the efficient transfer of materials and components critical to the manufacture of energy transition technologies, as well as on finished products. These barriers include high tariffs and restrictive regulations that affect both the efficiency and cost of cross-border operations, significantly increasing the costs of imported components needed to produce renewable technologies. This not only affects the market competitiveness of final products produced in LAC, but also hinders the adoption of renewable technologies within the region due to higher prices.

On the other hand, such measures may weaken markets and discourage investors and companies seeking to participate in the regional value chain. This could further complicate the progress of the energy transition in the region.

5.3 Recommendations

Domestic public policies, incentives, deductions and education

Targets and incentives for renewable energy production:

The public sector in LAC can strengthen the market for renewable energy technologies through the implementation of targets for renewable energy production and consumption either on an aggregate basis or more specific sectoral targets for the public, industrial and commercial sectors. A good example of this type of effort is the RELAC initiative² (Renewables in Latin America and the Caribbean) where 16 countries in the region have set a voluntary regional target of at least 80% renewable electricity in their electricity matrices by 2030 and 36% renewable energy in the total energy supply by 2030. Also, tariff schemes that incentivize energy generated by renewable sources can ensure an attractive economic return for new projects, thus encouraging greater private sector participation. This recommendation on targets and incentives is aligned with the principles of transparency, diversification, security and sustainability promoted by the 2022 Supply Chain Ministerial, an initiative launched in 2022 that seeks to strengthen the resilience of global supply chains through international cooperation among 31 economies, including the United States, the European Union, Japan, Mexico and several countries in Latin America, Europe and Asia. It also complements the objectives of the Americas Partnership for Economic Prosperity, also launched in 2022, which promotes inclusive and resilient economic growth in the Americas, focusing on strengthening trade, investment and cooperation in key areas such as energy and sustainable infrastructure, thereby generating shared prosperity and long-term development in the region.

Incentives for the consumption of technologies for the energy transition:

The public sector can promote local consumption of renewable technologies by implementing tax incentives for consumers who opt for these technologies. Increasing the costs of conventional technologies through higher taxes on fossil fuels can make renewable energies more competitive. In addition, setting stringent energy efficiency and emissions standards for vehicles, appliances and buildings can significantly boost the adoption of clean solutions. These policies, combined with public education and awareness of the benefits of these technologies, can transform the market and create a more sustainable environment that is less dependent on polluting energy sources.

Cooperation with the private sector

Tax incentives and favorable regulatory frameworks:

Design tax incentives that stimulate private investment in renewable energy projects, such as credits and exemptions. These can help reduce capital costs and improve the profitability of projects, which in turn can further attract investment. In addition, work can be sought with the private sector to develop clear regulatory frameworks that encourage investment in these technologies. This may involve simplifying permitting procedures, reducing bureaucratic processes and creating incentives to participate in these markets.

² The IDB holds the role of Technical Secretariat for the initiative. More details can be found at: https://hubenergia.org/es/relac

Creation of public-private dialogue platforms:

Establish public-private dialogue platforms where government and business actors can collaborate in identifying opportunities and challenges in the energy transition technologies market. These platforms can serve as spaces for policy discussion, identification of areas of cooperation and promotion of strategic partnerships between the public and private sectors.

Public tenders and concessions to boost market share

Opening up electricity production and auctions: LAC governments can make use of their purchasing power by strategically implementing public tenders and concessions. For example, by opening their production markets and implementing energy auctions, agreeing on the future purchase of renewable energy. This method ensures a stable market for renewable energy producers, providing certainty and predictability for investors to finance green energy projects. Auctions can be designed to prioritize or favor specific technologies, such as solar or wind, adapting to each country's energy needs, resources and priorities.



Public tenders and concessions:

Public tenders and concessions are powerful tools that governments can use to drive emerging markets related to the energy transition, such as EVs, solar panels, and residential or commercial batteries. Through their purchasing power, governments can establish selection criteria that favor companies that not only offer efficient technological solutions, but also meet rigorous environmental standards and contribute to local economic development. This could include local content requirements, incentives for energy efficiency innovation, and long-term commitments that facilitate the planning and expansion of critical infrastructure to support these new markets.

Regional cooperation for economic integration and equitable development

Economic cooperation and trade integration:

LAC governments can strengthen the regional market through regional cooperation focused on economic integration and equitable development. A key step would be to work toward greater trade integration by negotiating regional trade agreements that facilitate the reduction of tariffs and the elimination of non-tariff barriers. This approach promotes a more open and collaborative marketplace and increases the competitiveness of products manufactured in the region. Inspired by agreements such as the T-MEC, countries could adopt provisions that favor the purchase of regional products, such as Rules of Origin³ and other specific incentives, which would help consolidate domestic industry and protect it from international competition.

³ The Rules of Origin established in the T-MEC are criteria that determine whether a product is considered to originate in one of the member countries, guaranteeing that only regional products receive preferential tariff treatment and promoting regional industry. The main mechanism consists of defining the minimum percentage of the total value of the products that must be produced in one of the member countries to be considered regional. For example, in the case of automobiles, the minimum percentage of regional content to receive preferential tariff treatment is 75%.

Addressing uneven development:

To address unequal access to the benefits of renewable markets, it would be essential to implement deeper regional collaboration to share knowledge, technology and resources more effectively. Implementing integrated policies and fiscal incentives at the regional level could standardize market development across the region, fostering equitable growth. In addition, setting common targets for renewable energy adoption and creating harmonized regulatory frameworks could strengthen the resilience of supply chains and ensure that all member countries benefit equitably, promoting sustainable and inclusive development across the region.

Investment in production to develop the regional market

Strengthening local production:

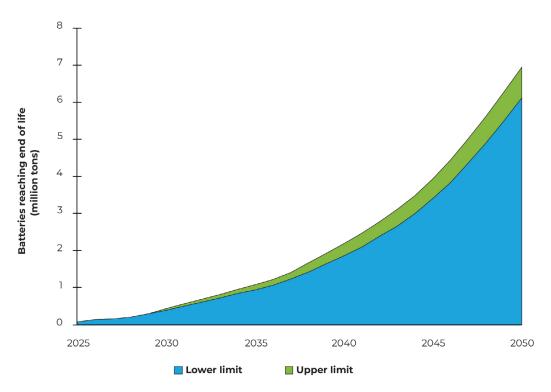
One of the key actions that LAC governments can implement is to stimulate investment in local production, through tax incentives, subsidies and preferential financing, to supply local and international demand.

Leveraging exports:

Securing and strengthening the position in LAC export markets, such as the U.S., is a crucial strategy to drive sector growth. The high demand and favorable prices achieved in these regions offer a strategic opportunity to justify the investment costs necessary to adapt and expand regional manufacturing capabilities for high value-added components. The use of surplus funds and favorable export prospects could be channeled to boost the transfer of knowledge and advanced technology to the region, as well as to develop technologies that meet the needs and purchasing power of the population in the region.



Lithium-ion batteries (LIBs) are essential to achieve the goals set by national and international energy transition strategies. In LAC, the demand for batteries has experienced steady growth due to the accelerated increase in the sale of electronic devices, as well as the drive for renewable energies and EVs (López Soto et al., 2022). This has led to a proportional, albeit lagged, increase in the number of LIBs that are beginning to be discarded in the region. It is estimated that between 2024 and 2050, between 6 and 7 million tons of used batteries will be generated in the region.⁴



Projected growth of the total mass of batteries reaching the end of their useful life in LAC, from electronic devices, EVs and electric storage. Source: (López Hernández et al., 2024).

This increase makes the proper management of end-of-life LIBs increasingly critical, requiring the adoption of reuse and recycling practices in the short term, as well as the creation of regional value chains for the valorization of this new type of input. However, **at present only 55% of all solid waste produced in LAC is adequately managed.** This, together with the lack of robust regulatory frameworks focused on managing used batteries (ULIB), reveals important areas of opportunity for the implementation of coordinated strategies to improve waste management and maximize its use.

The three key activities for ULIB end-of-life management that will be critical to drive are **collection**, **reuse** and **recycling**. **Collection** of used batteries involves establishing reverse logistics systems to collect them safely and efficiently, minimizing the number of used batteries that are inappropriately disposed. **Reuse** is about repurposing batteries once they are no longer suitable for their original use. For example, electric vehicle batteries for use in energy storage systems, thus extending their useful life and reducing the need for new batteries. Finally, **recycling** involves disassembling and processing batteries to recover valuable materials that can be used in the manufacture of new products. The main recoverable materials derived from ULIBs are aluminum, copper, cobalt, nickel, lithium and manganese.

For a more detailed analysis of end-of-life strategies for lithium batteries see López Hernández et al., 2024.

6.1 Opportunities

An appropriate and timely regulatory and legislative response, promoting the proper management, reuse and recycling of LIBs, can have numerous positive long-term environmental, social and economic impacts for the region.

Our estimates indicate that by 2050, the implementation of measures to promote the proper management, reuse and recycling of batteries has the potential to increase the useful life of up to 2.1 million tons of ULIB, postponing their disposal, and to recycle up to 2.3 million tons of ULIB, taking advantage of the regional valorization of their components. Based on these estimates, by 2050, ULIB recycling in LAC could represent between US\$3 billion and US\$5 billion, taking as a reference the market price of the different metallic components of batteries in 2021. Likewise, considering the unit value of new LIBs, the costs associated with collection and handling, and the estimated market value of reused batteries, the reuse of ULIBs could represent a value of up to US\$11.3 billion for LAC.

Thus, promoting the proper end-of-life management of batteries in LAC would not only help to reduce and manage the volume of waste batteries, but also represents an opportunity for the creation of a sustainable value chain for this material, taking advantage of new growth opportunities in the global market for critical materials. However, in addition to the potential direct logistical and economic value, there are significant areas of opportunity and indirect socio-environmental benefits that are difficult to quantify but enormously valuable.

Reduction of environmental and public health impacts



ULIBs contain toxic substances that, if not properly stored and exposed to the elements, can begin to leak substances that contaminate soil, water sources, and prove harmful to human health (Sojka et al. 2020; Stahl et al. 2018). In addition, ULIBs with some residual load may experience overheating, which can lead to fires or explosions (Dragonfly Energy 2022). These fires have been reported to lead to the loss of other recyclable materials, as well as the emission of greenhouse gases and the formation and release of a wide range of pollutants and toxic gases that pose a direct threat to human health and other organisms (Mrozik et al. 2021). Therefore, ensuring proper disposal, reuse and recycling can significantly reduce the environmental and human health impact of a disorderly flow of these types of batteries.

Reduction of pressure on the mining sector and the exploitation of primary minerals

As we have seen above, the exploitation of lithium resources is expected to increase rapidly in LAC. Therefore, **making use of waste batteries could reduce the demand for virgin lithium,** thus reducing the pressure on the growth of the regional mining industry and the associated environmental impacts.

Sustainable value chain development and job creation

The development of a robust ULIB reuse and recycling industry can generate direct and indirect employment opportunities in various sectors, including reverse logistics collection, recycling, of battery management, and application of recycled materials. It will increase the need for skilled labor not only on the operational side, but also in areas of academic and technical knowledge, including economists. environmental experts, technical staff and engineers in electromobility, stationary storage, battery management systems, battery control and system integration, battery testing, battery application, battery handling and safety, among others (Fraunhofer; EIT Raw Materials 2021).



Globally, it is estimated that a robust ULIB reuse and recycling industry would generate up to 10 million jobs by 2030, especially in developing countries (Global Battery Alliance; WEF 2019). Thus, encouraging the proper management and reuse and recycling of batteries in LAC would not only help mitigate their environmental and public health risks, but represents an opportunity for the creation of a wide range of skilled and unskilled jobs to serve a nascent industry that takes advantage of the growing global market for critical materials.

Regional cooperation to strengthen reuse and recycling capabilities

Regional cooperation in the development of an end-of-life battery management strategy in LAC is critical to address the common challenges faced by countries in the region. A collaborative approach will improve capacities, facilitate the cross-border movement of batteries and promote investments for more efficient collection, recycling and reuse of ULIB, especially in smaller countries that lack the volumes of ULIB needed to justify investments in infrastructure and capacity building of their own. In this way, adopting intraregional regulations and management systems for ULIB management, as well as prioritizing a sustainable reuse and recycling industry, will not only mitigate environmental risks, but will also slow down the exploitation of mineral deposits and make it possible to locally valorize these products at the end of their useful life, thus promoting sustainable economic growth in LAC.

6.2 Challenges

LAC is in a favorable position to initiate the development of a value chain focused on the recycling of used batteries. This is because it has abundant human capital trained in mineral extraction, established commercial relationships, and an incipient refining industry that could be adapted for the valorization of ULIB minerals. However, to ensure the success of these value chains, significant challenges still facing the region must be addressed.

Lack of sound regulatory frameworks

There are few specific regulations for ULIB management and processing in the region. Most of the existing regulations refer to waste batteries from electrical and electronic devices, such as cell phones and computers, and are not adequate to address the management of larger batteries, such as vehicle or industrial batteries. In addition, existing regulatory frameworks are based on voluntary measures with no mandatory requirements, and those few measures that are mandatory and in place are often not effectively enforced. This is critical because, under current conditions, ULIB recycling is not sufficiently profitable to justify investments from the private sector and, therefore, the existence of regulatory frameworks that create incentives to make ULIB valorization viable is necessary for the development of a value chain.

Several LAC countries have **national electromobility strategies to** increase the demand for EVs and reduce the environmental impact of transportation. However, **the main focus is on the demand and use of electric cars, omitting the management of their components at the end of their useful life.**

Poor regional cooperation

Regional cooperation in LAC plays a key role in the proper management of ULIBs. The region is home to the largest global reserves of lithium and other strategic minerals, so maximizing the local valorization of ULIBs would be highly beneficial, as it would reduce the need to exploit new deposits and their socio-environmental impact.

However, the lack of a robust and coordinated regulatory framework for the management of this resource represents a critical challenge to improve collection and processing capabilities, facilitate and track transboundary movements of batteries and promote investments between countries for a more efficient management of ULIBs.

The regional approach is particularly important for small countries, which lack sufficient volumes of ULIB to justify investments in their own management capacities. **Regional cooperation can help achieve the economy of scale needed to make investments in recycling and reuse infrastructure viable.**

Currently, regional cooperation to improve ULIB management practices is minimal, except for some ongoing bilateral trade agreements.

Finally, compliance with Basel Convention regulations is excessively complicated and costly for small and medium-sized companies, which hinders regional cooperation in ULIB matters.

Small and medium-sized enterprises, both formal and informal, involved in the collection and sale of automotive waste or waste electrical and electronic equipment (WEEE), which could handle ULIBs, do not have the administrative capacity to comply with the legal requirements of the Prior Informed Consent procedure for transboundary movements of batteries. This reduces the incentive to collect ULIBs in countries that do not have their own recycling capabilities. In addition, the possibility of exporting used batteries to recycling companies in the region, which could process higher volumes, is also limited by these administrative obstacles.

Lack of investment

The lack of investment in ULIB management development presents several challenges that limit the region's ability to adequately manage these batteries.

First, the vast majority of ULIB recyclers that exist in LAC are limited to the initial mechanical stages, such as shredding and separation. Therefore, there is a high dependence on the refining and recovery capacities of valuable materials from more developed regions such as the USA, Europe and Asia. This external dependence reduces the autonomy and valorization capacity of the region, hindering the development of a sustainable ULIB value chain in the region.

For example, the absence of lithium recovery processes in LAC results in collectors having to send large shipments of used batteries, either whole or crushed, to other regions with a more developed industry where they have the capacity to process and refine them. This shifts the potential for secondary lithium production to those regions and creates a technological and knowledge gap in the region that hinders the development of a circular economy.

Another major looming issue is the shift in battery composition towards technologies of lower material value such as lithium iron phosphate (LPF) batteries. These types of batteries reduce the cobalt content compared to more established technologies in the region such as lithium manganese oxide (LMO), lithium nickel manganese cobalt (NMC) and lithium nickel cobalt aluminum (NCA) batteries, making them significantly less expensive and therefore very attractive for the primary market. However, for the secondary market, the reduction of valuable materials could make recycling processes less profitable, requiring additional investments or the implementation of financial instruments to ensure the economic viability of this industry in the region.

Finally, the lack of investment and the short-term focus of investors in LAC constitute an additional barrier to the development of ULIB recycling capacities. As an incipient resource, there are not yet sufficient volumes of batteries, nor well-defined regulatory frameworks to motivate investment in this industry. The lack of long-term commitment and the search for immediate remuneration limit the availability of funds to establish or expand recycling plants in the region, further hindering efforts to develop proper ULIB management.

In summary, the lack of investment in the development of ULIB management in LAC presents significant challenges that require a coordinated and strategic response to overcome them and move towards sustainable management of these batteries at the end of their useful life.

6.3 Recommendations

A series of recommendations are proposed below to address the challenges identified in the previous section and facilitate the development of a robust ULIB management system in LAC.

Regulatory frameworks

Implementation of mandatory regulatory frameworks for reuse and recycling:

Assist public sector entities to integrate requirements for LIBs into national waste management regulations, including the development of national strategies for safe and environmentally responsible long-term management of these batteries.

Extended Producer Responsibility (EPR) systems:

Support key stakeholders, such as battery producers, government agencies and waste management companies, in establishing and improving mandatory Extended Producer Responsibility (EPR) systems for batteries, with clear collection, reuse and recycling targets, as well as defining incentives and penalties for their practical implementation.

Minimum quality requirements for used batteries:

Create specific provisions to regulate the use of second-life batteries to ensure that these batteries are tested to meet quality standards before being resold. This regulation will assure end users that second-life batteries meet minimum quality requirements.



Minimum requirements for recycled materials:

Support public entities in introducing mandatory recovery rates and in developing regulations to ensure that new batteries placed on the market in LAC contain a certain proportion of recycled materials.

Compliance with the Basel Convention:

The Convention establishes sanctions that restrict transboundary transfers of hazardous materials, including those derived from ULIBs, preventing the accumulation of environmental impacts, especially in less developed countries that may be more vulnerable. A region committed to the convention and with robust regional control can promote a more sustainable supply chain, generating confidence in markets and investors by supporting an industry with responsible environmental practices.

Transparency of data and information from the public and private sectors:

Implement legislative and technological infrastructure, aligned with the EU Battery Passport⁵, to facilitate the requisitioning of data on the volumes, types and characteristics of ULIBs generated by the public and private sectors in the different countries of the region. The objective of this measure is to improve traceability and transparency in the ULIB supply chain, promoting the circularity of materials and minimizing the environmental impact of their reuse and disposal. In addition, transparency would contribute to generating confidence in markets and investors, thus promoting the sustainable development of the industry in the region.

Disclosure

Regional networking with actors from the public sector, industry and research:

Holding regional conferences to share practices and technologies on ULIB management and encourage the creation of national and local groups to find circular solutions for batteries, especially where ULIB is expected to increase and current regulation is insufficient. These groups would facilitate cooperation between the public and private sector, promoting knowledge sharing and supporting the development of specific regulations for ULIB management.

Promote outreach, education and training about the resource:

Design of a communication strategy to promote the importance of proper management of lithium batteries and available collection schemes.

Development of recycling and reuse infrastructure

Support for pilot projects:

Support new and existing pilot projects for battery reuse and recycling in the region. This may include technical assistance for knowledge transfer and capacity building, in collaboration with national and international cooperation partners, universities and private sector actors.

Investment to strengthen existing projects:

Mobilize investment and financing to expand the operations of small and medium-sized enterprises with environmentally sustainable recycling or reuse capacity. At the same time, provide technical assistance to ensure the transfer of technology and knowledge on best operating practices for ULIB management.

Strengthen knowledge-sharing networks:

Support industry associations for knowledge sharing by providing technical assistance to expand their reach.

Operational standards:

Establish mandatory standards outlining proper recycling and reuse operations, ensuring that only properly operating facilities are approved and supported.

The European Union Battery Passport is a regulatory framework that sets standards for traceability and transparency in the battery supply chain in the European Union. This system seeks to facilitate the exchange of information on batteries and their components throughout their life cycle, from production to recycling. The amendment to the EU Battery Regulation was adopted in July 2023, establishing that from February 2027 all batteries over 2kWh sold in the EU will be required to have their battery passport, a digital register that includes all relevant characteristics for the optimal management of LIBs. (European Parliament and Council of the European Union 2023).

Support for human resources education and training

Training of decision makers:

Provide specific trainings for key actors in the public, private and civilian organization sectors related to LIB collection and transport on guidelines and procedures for safe transport.

Support for research and development:

Support research and development initiatives and pilot projects to identify innovative mechanisms, methodologies and approaches for the safe and environmentally sustainable management of ULIBs.

Strengthen knowledge exchange networks:

Train national authorities and environmental institutions on best practices for ULIB management, as well as on monitoring and reporting criteria for the control of these practices through national regulatory frameworks.

Training of sector operators:

Implement programs to train collectors, transporters and other key public sector actors in the requirements for compliance with the Basel Convention for the transboundary movement of waste, with the objective of streamlining and supporting the process and facilitating the movement of ULIBs to appropriate facilities that may be in other parts of the region.



CONCLUSION

Global decarbonization strategies require much greater use of lithium batteries, solar panels and wind turbines, opening a unique opportunity for LAC to sustainably boost its socioeconomic development.

LAC **concentrates very relevant and significant portions of many of the world's critical minerals,** especially lithium, copper, graphite and rare earths. The exploitation of these minerals requires companies to have a social license, so the mining sector must go beyond national legislation on environmental and social issues and communicate constantly with local communities. Environmental and social factors, rather than economic ones, may be the major constraint in capturing benefits for LAC.

LAC can and should expand its global influence and **capture greater benefits in the value chain.** To do so, it must exploit its comparative advantages: mineral reserves, skilled labor, strategic positioning as a trade ally of the United States and Europe, and access to port infrastructure for exports. As LAC consolidates its dominant position in mineral extraction, it can develop greater refining capacity by taking advantage of local mineral production at high grades, the potential for renewable energies at lower cost and with a smaller carbon footprint, and by promoting greater training and education in technical areas. Similarly, strategic alliances between countries in the region are key to competing globally in the value chains of decarbonization technologies.



With abundant natural resources, skilled labor and productive and export capacity already established in some countries, LAC is well positioned to capitalize on the growing global demand for energy transition technology. However, despite its potential, the region must seek to increase investment in advanced technologies, promote regional integration to increase resilience in its supply chains and develop its industrial capabilities, to consolidate itself as a key player in the global renewable energy market. The region's manufacturing of renewable technologies and their components offers great opportunities for sustainable economic development and job creation, while strengthening the region's energy sovereignty and helping to mitigate global climate change.

Global demand for energy transition technologies is in a period of accelerated growth, driven by national and international initiatives to address climate change. With an estimated doubling in demand for electric power by 2030, coupled with a significant increase in the adoption of electric vehicles, both LAC's domestic market and its main export markets present significant growth opportunities that the regional industry should be prepared to address. However, challenges such as unequal access to market benefits and dependence on international suppliers highlight the need for concerted policies to strengthen regional capacity and ensure a sustainable and equitable energy transition across the region. Regional cooperation and public policies can further boost market development by reducing trade barriers and promoting local production.

Finally, with a growing volume of used lithium batteries in LAC, driven by the rise of electronic devices, renewable energy and electric vehicles, the region must proactively address the end-of-life challenge of these batteries. By implementing reuse and recycling practices, as well as creating regional value chains for the processing and valorization of critical components and materials, LAC can not only efficiently and safely manage the growing volume of discarded LIBs, but also seize a new opportunity for economic growth. By implementing mandatory regulatory frameworks, strengthening regional cooperation, encouraging investment in recycling and reuse infrastructure, and training human capital, LAC can reduce the environmental impacts of this waste product while promoting employment, industrial development and economic growth in the region.

In summary, LAC can contribute to global decarbonization by actively participating in the emerging value chains of critical minerals and energy transition technologies. To take full advantage of this opportunity for industrial, economic and social development, multiple economic, investment, environmental and social barriers must be overcome. Regional cooperation, proactive participation of governments and the private sector, investment in capacity and education and training at all levels are key to strengthening value chains and competing globally as a hub for the development of critical minerals and the technologies needed for the energy transition. It is imperative that LAC act with the appropriate public policies and investment to take a definitive step towards the region's development in the coming decades.

References

Ambrose, H.; Kendall, A. (2020). Understanding the future of lithium: Part 1, resource model. Journal of Industrial Ecology, 24(1), 80-89.

ArgentinaGob. (2024).). Global lithium dashboard - Lithium mining projects. https://www.argentina.gob.ar/economia/mineria/siacam/tablero-global-del-litio. Accessed on: 10/05/2024.

Bacanora Lithium. (2024). Sonora Lithium Project - Overview. https://bacanoralithium.com/sonora_lithium_project/default.aspx. Access date: 10/05/2024.

IDB. (2020). Towards a new shared vision on the extractive sector and its role in the sustainable development of Latin America and the Caribbean. *Inter-American Development Bank.*

Spano, C.; Natali, P.; Cannon, C.; Greene, S.; Urzúa, O.; Sucre, C.; Unzueta, A.. (2021). Latin America and the Caribbean 2050: becoming a global hub for low-carbon solutions and metals. *Inter-American Development Bank*.

Balza, L.; Diaz, L.; Gómez-Parra, N.; Manzano, O. (2021). The unwritten license: social license to operate in Latin America's extractive sector. *Inter-American Development Bank*.

IDB. (2022). Leveraging Demand Growth in Minerals and Metals for the Transition to a Low-Carbon Economy. *Inter-American Development Bank*.

Sanin, M.E.; Snyder, V.; Walter, M.; Balza, L. (2023). From lithium to electric vehicles in Latin America and the Caribbean. *Inter-American Development Bank*.

IDB. (2023). Energy transition as an opportunity for green industrial development in Latin America and the Caribbean: Policy recommendations and roadmap. *Inter-American Development Bank*.

López Hernández, V.; Hilbert, I.; Gascón Castillero, L.; Manhart, A.; García, D.; Nkongdem, B.; Dumitrescu, R.; Sucre, C.; Ferreira Herrera, C. (2024). Recycling and Reuse of Lithium Batteries in Latin America and the Caribbean: Analytical Review of Global and Regional Practices. *Inter-American Development Bank*.

Rojas-Hayes, C.; Casas, E.J.; Sucre, C. (2023). Green mining in Latin America and the Caribbean: Comparative analysis of public policies and industry standards to boost sustainability in mining. Inter-American Development Bank.

BloombergNEF (2022): Electric Vehicles Start Gaining Traction in Latin America. Online available at https://about.bnef.com/blog/electric-vehicles-start-gaining-traction-in-latin-america/

BNEF. (2023). Electric Vehicle Outlook 2023. BloombergNEF. https://about.bnef.com/electric-vehicle-outlook/

Castillo, E.; Eggert, R. (2020). Reconciling diverging views on mineral depletion: a modified cumulative availability curve applied to copper resources. *Resources, Conservation and Recycling*, 161, 104896.

CESCO. (2020)). Refined copper: A good business for Chile https://www.cesco.cl/wp-content/uploads/2021/07/Cobre-refinado.-Un-buen-negocio-para-Chile.pdf

Dragonfly Energy (2022): What Is Thermal Runaway in Batteries? Online available at https://dragonflyenergy.com/thermal-runaway/

THE EUROPEAN PARLIAMENT AND THE COUNCIL OF THE EUROPEAN UNION. 2023. "REGULATION (EU) 2023/1542 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 12 July 2023 on Batteries and Batteries and Their Waste and Amending Directive 2008/98/EC and (EU) 2019/1020 and Repealing Directive 2006/66/EC." Official Journal of the European Union. https://eur-lex.europa.eu/eli/reg/2023/1542/oj

Ember. (2023). Yearly Electricity Data (2023). Ember - European Electricity Review (2022); Energy Institute - Statistical Review of World Energy (2023) – with major processing by Our World in Data. https://ourworldindata.org/grapher/carbon-intensity-electricity

EU. (2024). Carbon Border Adjustment Mechanism. European Union. https://taxation-customs.ec.europa.eu/carbon-border-adjustment-mechanism_en

Fraunhofer; EIT Raw Materials (2021): Future expert needs in the battery sector.

Global Battery Alliance; WEF - World Economic Forum (2019): A Vision for a Sustainable Battery Value Chain in 2030 - Unlocking the Potential to Power Sustainable Development and Climate Change Mitigation. Geneva.

GlobalPetrolPrices. (2023). Electricity prices. https://www.globalpetrolprices.com/electricity_prices/

Goldman Sachs. (2023). Direct Lithium Extraction: A potential game changing technology. https://www.goldmansachs.com/intelligence/pages/gs-research/direct-lithium-extraction/report.pdf.

Graham, N.; Malagón, E.; Viscidi, L.; Yépez, A. (2021): State of Charge: Energy Storage in Latin America and the Caribbean: Inter-American Development Bank. Online available at https://publications.iadb.org/en/node/30110

Greim, P.; Solomon, A. A.; Breyer, C. (2020). Assessment of lithium criticality in the global energy transition and addressing policy gaps in transportation. *Nature communications*, 11(1), 4570.

Ritchie, H. (2020). Sector by sector: where do global greenhouse gas emissions come from? https://ourworldindata.org/ghg-emissions-by-sector.

 $IEA. (2023a). Critical Minerals Market Review 2023. {\it International Energy Agency}. \\ \underline{https://www.iea.org/reports/critical-minerals-market-review-2023}. \\ \underline{https://www.iea.org/reports/critical-m$

IEA. (2023b). Sustainable and Responsible Critical Mineral Supply Chains. International Energy Agency. https://www.iea.org/reports/sustainable-and-responsible-critical-mineral-supply-chains, License: CC BY 4.0

IEA. (2024). Global Critical Minerals Outlook 2024. International Energy Agency. https://www.iea.org/reports/global-critical-minerals-outlook-2024

IGF. (2021). Three Emerging Policy Trends for Critical Minerals in Latin America. *Intergovernmental Forum on Mining, Minerals, Metals and Sustainable Development*. https://www.igfmining.org/three-emerging-policy-trends-for-critical-minerals-in-latin-america/

IPCC. (2022). Chapter 12: Central and South America. Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 1689–1816, doi:10.1017/9781009325844.014.

IRS. (2022). Inflation Reduction Act of 2022. United States Government. https://www.irs.gov/inflation-reduction-act-of-2022

Khakmardan, S.; Rolinck, M.; Cerdas, F.; Herrmann, C.; Giurco, D.; Crawford, R.; Li, W. (2023). Comparative Life Cycle Assessment of Lithium Mining, Extraction, and Refining Technologies: a Global Perspective. *Procedia* CIRP, 116, 606-611.

Kottohoff, K. (2020). Mineralogy of tailings deposits in Chile and relationship with source deposits: potential for recovery of valuable elements. *University of Chile, Department of Geology.*

López Soto, D.; Mejdalani, A.; Chueca Monteruga, E.; Hallack, M. (2022): The Energy Roadmap for Latin America and the Caribbean. Inter-American Development Bank (IDB). Online available at https://publications.iadb.org/publications/spanish/document/La-ruta-energetica-de-America-Latina-y-el-Caribe.pdf

Mrozik, W.; Rajaeifar, M. A.; Heidrich, O.; Christensen, P. (2021): Environmental impacts, pollution sources and pathways of spent lithium-ion batteries. In: Energy Environ. Sci. 14 (12), pp. 6099-6121. DOI: 10.1039/DIEE00691F

Ramji, A.; Dayemo, K. (2024). Releasing the Pressure: Understanding Upstream Graphite Value Chains and Implications for Supply Diversification. *UC Davis Institute of Transportation Studies*. https://escholarship.org/uc/item/0q83t5fd

Sojka, R.; Pan, Q.; Billmann, L. (2020): Comparative study of Lithium-ion battery recycling processes. ACCUREC Recycling GmbH (ed.). Online available at https://accurec.de/wp-content/uploads/2021/04/Accurec-Comparative-study.pdf

Solar Cluster. (2015). Green Silicon: Feasibility of fully integrated vertical production of photovoltaic modules in Brazil and Paraguay.

South32. (2023). Annual Report 2023. https://www.south32.net/docs/default-source/annual-reporting-suite/2023/annual-report-2023.pdf

Stahl, H.; Baron, Y.; Hay, D.; Hermann, A.; Mehlhart, G.; Baroni, L.; Rademaekers, K.; Williams, R.; Pahel, S. (2018): Study report in support of evaluation of the Directive 2006/66/EC on batteries and accumulators and waste batteries and accumulators, Final Evaluation Report. European Commission (ed.). Online available at https://op.europa.eu/o/opportal-service/download-handler?identifier=d2141777-dc01-11e8-afb301aa75ed71a https://op.europa.eu/o/opportal-service/download-handler?identifier=d2141777-dc01-11e8-afb301aa75ed71a https://op.europa.eu/o/opportal-service/download-handler?identifier=d2141777-dc01-11e8-afb301aa75ed71a https://op.europa.eu/o/opportal-service/download-handler?identifier=d2141777-dc01-11e8-afb301aa75ed71a https://opeortal-service/download-handler?identifier=d2141777-dc01-11e8-afb301aa75ed71a https://opeortal-service/download-handler?identifier=d2141777-dc01-11e8-afb301aa75ed71a https://opeortal-service/download-handler?identifier=d2141777-dc01-11e8-afb301aa75ed71a https://opeortal-service/download-handler?identifier=d2141777-dc01-11e8-afb301aa75ed71a <a href="https://opeortal-service/download-handler?identifier=d2141777-dc01-11e8-

Trost, J. N.; Dunn, J. B. (2023). Assessing the feasibility of the Inflation Reduction Act's EV critical mineral targets. *Nature sustainability*, 6(6), 639-643.

United Nations Statistics Division. 2024. "UN Comtrade Database [Online Database] https://comtrade.un.org/data/.

USGS. (1996). Mineral Commodity Summaries 1996. United States Geological Survey. https://www.usgs.gov/centers/national-minerals-information-center/mineral-commodity-summaries

USGS. (2023). Mineral Commodity Summaries 2023: Appendix C Reserve and Resources. *United States Geological Survey*. In Mineral Commodity Summaries 2023. https://doi.org/10.3133/mcs2023

USGS. (2024). Mineral Commodity Summaries (Bauxite, Copper, Graphite, Iron-ore, Lithium, Manganese, Nickel, Rare earths, Silicon, Zinc). *United States Geological Survey*. https://pubs.usgs.gov/periodicals/mcs2024/

USTR. (2024). Free Trade Agreements. Office of the United States Trade Representative. *United States Geological Survey*. <a href="https://ustr.gov/trade-agreements/free-trade-

Vikström, H.; Davidsson, S.; Höök, M. (2013). Lithium availability and future production outlooks. Applied energy, 110, 252-266.

Zhang, C.; Yan, J.; You, F. (2023). Critical metal requirement for clean energy transition: a quantitative review on the case of transportation electrification. *Advances in Applied Energy*, 9, 100116.

