American Journal of Environmental and Resource Economics
2026, Vol. 11, No. 3, pp. 48–59
https://doi.org/10.11648/j.ajere.20261103.11

Research Article

Ethiopia's Strategic Pathway to Competitiveness in the Lithium-ion Battery Value Chain: A Comprehensive Analysis and Strategic Recommendations

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Abstract

This paper examines Ethiopia's potential to participate in the lithium-ion battery (LIB) industry, a sector that is increasingly important for decarbonizing the country's transportation system through the adoption of electric vehicles. As Ethiopia seeks to expand electric mobility in the coming years, the development of battery-related industries will be critical to supporting this transition. To assess the country's readiness and competitive potential, the study employs value chain analysis alongside SWOT and Porter's Five Forces frameworks to evaluate the strengths, weaknesses, opportunities, and threats across the upstream, midstream, and downstream segments of the LIB value chain. The findings highlight Ethiopia's significant natural resource potential, particularly its lithium brine reserves in the Danakil Basin of the Afar Region, which are estimated at approximately 3 million tons with a recovery rate of about 50%. In addition to lithium, the country possesses other strategic battery minerals, including nickel and graphite, which could strengthen its position within the global battery supply chain. The analysis suggests that lithium brine extraction offers the most feasible entry point into the LIB value chain, as it requires comparatively lower infrastructure and capital investment than graphite and nickel processing. However, the study also identifies several challenges that must be addressed for Ethiopia to fully benefit from the growing LIB industry, including substantial investments in infrastructure, advanced technologies, skilled human resources, and industrial-scale production capabilities. Based on these findings, the paper proposes strategic recommendations to enhance Ethiopia's competitiveness in the global lithium-ion battery market and provide policymakers, industry stakeholders, and investors with insights into the opportunities, constraints, and pathways for establishing a sustainable and competitive LIB value chain.

Keywords

Lithium-ion Battery Industry, Electric Vehicles, Lithium Brine Reserves, Strategic Advantage, Value Chain Analysis, Ethiopia Potential, Competitiveness

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Received: 5 June 2026; **Accepted:** 6 July 2026; **Published:** 11 August 2026

1. Introduction

1.1. Background

The worldwide demand for LIBs has been increasing which is mainly attributed to the adoption of electric vehicles, storage systems for renewable energies, and portable electronics. Ethiopia has been an underrepresented player in the LIB value chain and as a min -erals rich country wants to exploit its resource potential and assess its competitiveness. This paper examines Ethiopia's mining policies, industrialization strategies, and possibilities for renew -able lithium extraction in the context of a strategic road map for the establishment of a competitive LIB value chain.

This paper builds on results previously published from [5] Master's thesis, with significant rewriting, updating, and reanalysis of data to appeal to a more general audience. Additional review of literature and theoretical frameworks inspired more analysis to increase applicability for policy makers and industry practitioners as well as for the global research community.

In line with Ethiopia's Ten-Year Transport and Logistics Perspective Plan, the country seeks to make a shift toward sustainable mobility via deployment of 4,850 e-buses and 148,000 small electric vehicles [15]. With more electric vehicles on the road, there will be a lot more demand for batteries to replace and supply them. Currently, batteries make up almost 40% of an electric car's weight and close to 50% of its cost. These batteries have high energy efficiency, a mean average driving distance of about 150 km, a velocity of 120 km/h, and a life time of about 2000 recharge cycles which to about five years of work [10] Hence, it is vital to analyze Ethiopia's position and competitiveness in LIB value chain to face future demand.

While Ethiopia has the significant mineral resources needed for battery production, the East African country has, so far, made little headway along the LIB value chain. One of the problems is lack of knowledge about Ethiopia's situation at the upstream, mid-upstream and downstream of this industry. it is difficult to identify Ethiopia's strengths, weaknesses, and areas needing improvement. Additionally, the country encounters obstacles related to technology transfer, infrastructure development, and market access. The lack of clear strategic interventions hinders Ethiopia's ability to attract investments, foster innovation, and create a conducive business environment for the LIB industry.

Therefore, an analysis of the full value chain will be needed to focus on bottlenecks and potentials for Ethiopia in the industry of LIB. Several research questions are answered by this study, such as, what are the predominant processes of the lithium-ion battery value chain? The study also aims to identify a strategic framework that would enable Ethiopia to capitalize on its competitive advantages in particular segments of the LIB value chain.

With global shift to renewable energy and electric mobility, countries worldwide are pouring billions into the LIB industry. Ethiopia also anticipates rising domestic battery demand as electric mobility grows. But there is still a little study about how competitive Ethiopia in this area.

Literature also shows lithium brine and evaporite deposits in Ethiopia [7], indicating a high prospect for resource exploitation. However, a full-scale examination is necessary to assess what part of batteries Ethiopia can play in the global battery value chain. Such research could guide policy, attract investment, contribute to economic development, and support meeting both local and worldwide needs for lithium-ion batteries.

This study presents a holistic value chain analysis which encompasses the phases of mining, raw material processing, production of battery components, technology development and end-of-life battery recycling. Through the use of strategic tools such as SWOT analysis and Porter's Five Forces model, the paper analyzes Ethiopia's strengths, opportunities and challenges by drawing, among other things, on expert opinion. It does a1so look into technological, infrastructural and environmentally- sustainable mining (toxic waste disposal included) bottlenecks.

In that regard, the research seeks to determine through this study, the LIB value chain segments in which Ethiopia can gain comparative advantage. The results will enable policy makers, investors, and other industry participants to make strategic decisions to attract investment and tap potential of Ethiopia's lithium resource in the growing global battery industry.

1.2. Problem Statement

Ethiopia's decarbonization of its fleet with thousands of electric vehicles under a ten-year plan will create considerable local demand for lithium-ion batteries (LIBs). Ethiopia has not exploited the LIB value chain though resources are plentiful on the one hand and on the other hand there was a lack of knowledge about its competitiveness, of threats and opportunities brought about by technology, infrastructure and market access. A detailed study of the upstream, midstream, and downstream segments is needed to pinpoint barriers and potential strategic interventions.

1.3. Research Questions

1) What are the main stages in the lithium-ion battery value chain?
2) How does Ethiopia fare currently in the global lithium-ion battery value chain?
3) What is Ethiopia's natural endowment and capacity to engage in the LIB value chain?
4) What strategic accord will realize the best value from

Ethiopia's comparative advantages across particular sub-sectors of the value chain?

1.4. Objectives

1.4.1. General Objective

To assess Ethiopia's competitiveness and develop a strategic framework for leveraging its advantages in the lithium-ion battery (LIB) value chain.

1.4.2. Specific Objectives

1) To analyze the processes involved in the lithium-ion battery value chain.
2) To assess the Ethiopia’s current status in the global value chain.
3) To evaluate LIB Ethiopia’s strengths.
4) Pick a strategic framework to exploit competitive advantages particular value chain segments.

1.5. Scope

This study considers Ethiopia’s competitive advantage in the LIB value chain, in terms of natural resources, capabilities, and domestic EV demand. The study investigates the technical and economic aspects of the material flow (from extraction to recycling) based on 2014-2030 data and previous value chain analyses.

2. Literature Review

2.1. Theoretical Framework: Battery Global Value Chain

The value chain includes all activities from design to the final user, such as the procurement of raw materials, processing, manufacturing, distributing, and managing after consumption [13]. Insights into the structure, performance and coordination among the various elements of the value chain are disclosed, clarifying how value is created and captured within industries - particularly relevant for developing countries attempting to achieve inclusive growth [9, 11].

The lithium-ion battery (LIB) supply chain consists of multiple stages: raw material acquisition (lithium, cobalt, nickel), processing and refining, parts and cell production, pack assembling, distribution, and end-of-life handling [4]. Following [8], the LIB chain demonstrates hybrid governance: producer-driven in capital-intensive stages (mining, refining, cell production) based on technology and scale, which involves high barriers to entry, and buyer-driven downstream, where massive sectors (EV producers, electronics organizations) dominate demand and requirements. Regional integration (e.g., AfCFTA) facilitates developing countries in transcending scale barriers through output aggregation and policy harmonization [1].

In addition to governance, chains like the LIB are challenged by sustainability issues: resource constraints and ethical issues (DRC cobalt, Lithi um Triangle water use), environmental damage, energy density and capacity fade technological constraints, suboptimal recycling, plus social/labor matters [4]. Emerging technologies solid-state batteries, silicon anodes, high-nickel cathodes, AI-enabled BMS are set to change power dynamics and value allocation.

The conventional framework of producer/buyer fails to account for opportunities to develop. The African Green Minerals Strategy proposes Equitable Resource-Based Industrialization (ERBI), which is represented through seven mineral linkages: backward (local procurement), forward (domestic processing), fiscal (revenue reinvestment), knowledge (skills, research), spatial (infrastructure, regional integration), lateral (cross-sectoral connections), and consumption linkages (local demand fueled by mineral incomes). These linkages orientate mining toward the "inverted pyramid" the oversea exports and foreign revenues versus the low employment it provides and requires a conscious shift in policy [2]. The Integrated Sustainability-Governance-ERBI Framework, developed by integrating these aspects, offers concepts to analyze the diversified chain configuration and a policy framework to transform mineral wealth into sustainable and inclusive development.

2.2. LIB’s Value Chain

The lithium-ion battery (LIB) supply chain is composed of several stages that are closely related, from raw material sourcing to battery recycling at the end of life. This value chain is often portrayed as a closed-loop since the materials included in spent batteries can be salvaged and re-used in the production, enabling more resource-efficient and environmentally sustainable battery production.

Among them the front-end of the LIB value chain, particularly the extraction of raw materials, processing, and manufacturing of components and cells, is seen to be the key stage. These phases are also the highest value-added phases due to complexity of technology, expertise requirement and high capital expenditure. They also require advanced technical capabilities and robust supply chain collaboration [14].

Therefore, in the light of this importance, the present study seeks to analyze each stage of the LIB value chain, separately, so as to gain deeper insights on the processes, players at each tier, and domain specific opportunities and challenges for engaging in the industry.

2.3. Overview of the LIB Cell Value Chain Stages

Table 1. *Overview of the Li-ion battery cell value chain stages.*

Stage	Raw Material	Processed Material	Electrode	Cell	Cell Assembly	Battery Pack	Recycling
Value Add	~80%	~50%	~40%	~50%	~25%	~30%	~10%
Key Success Factor	Continuous Access to mines	Process stability	Process speed	Welding/Automation degree	Automation efficiency	Process integration	Process efficiency

Source: [14]

2.4. The Various Stages in the LIB Value Chain

The LIB supply chain is composed of several interrelated sectors, from raw material mining to the recycling of spent batteries. Mining and processing raw materials, producing battery components, assembling battery cells and packs, and recycling batteries at end of life are the main activities across this chain. These activities constitute intricate industrial systems that include mining, chemical processing, advanced manufacturing and energy-related sectors.

Overall, the LIB supply chain can be broadly segmented into upstream, midstream, and downstream. The upstream phase deals with the mining and production of basic raw materials like lithium and other vital minerals, and their initial processing and refining. This is a fundamental stage because it ensures the primary inputs for battery production and because it determines to a high degree the supply and cost of the desired materials.

Battery component production and battery cell manufacturing are part of the midstream segment. This phase consists of such activities as cathode and anode material processing, electrolyte manufacture, separator production and battery cell assembly. High-tech industrial base the industry requires high technology, professional machinery and technical knowledge for improving the production, safety and performance of batteries.

The downstream is concerned with the assembly of battery cells into battery modules and packs and the delivery to end users in industrial applications mainly including electric vehicles, renewable storage systems, and consumer electronics. It also covers battery distribution, service and end-of-life handling including recycling and material reclaim. Good recycling is important to mitigate environmental damage and reclaim valuable materials for use in the manufacturing loop [6].

In summary, from raw material to finished cell, every segment of the value chain for the LIB requires a high level of capital intensity, technical knowledge, and complex interplay among diverse players for the production of the cells to be viable and for the production of high-quality battery products. The lithium-ion battery industry value chain flow is as follow:

Table 2. *The lithium-ion battery industry chain flowsheet.*

Raw Material Sourcing Lithium extracted from brine, spodumene, or lepidolite		Electrolyte Precursor $LiPF_6$ produced as a key electrolyte component		Battery Cell and Pack Assembly Battery cells assembled and integrated into packs		End User Deployment Certified batteries used in electronics, EVs, and storage
	Lithium Compound Production Extracted lithium converted into Li_2CO_3, LiOH, or LiCl		Battery Component Creation Cathode, anode, electrolyte, and separator materials manufactured		Quality Control and Certification Batteries tested and certified for quality and safety	

Source: [6]

Specific sources include research papers by [14], the International Energy Agency [3] reports from 2014 to 2022, as well as data from the Lithium-Ion Battery Market Size [12] on the global lithium-ion battery market.

1) Upstream Stage:
   a) *Extraction of Raw Materials:* the study will analyze the primary sources of critical raw materials for LIBs including lithium, cobalt, and nickel, with an emphasis on geographic concentration and supply risks. Processes of extraction and main producing countries (Australia, Chile, Bolivia, Argentina, and the Democratic Republic of the Congo) were studied.
   b) *Processing of Raw Materials:* The study will look at China's overwhelming role in processing raw materials (lithium, cobalt, graphite) into high-purity chemicals (lithium hydroxide, nickel sulfate) and in particular in processing.
2) Midstream Stage:
   a) *Manufacturing of Components:* the study will cover the production of important components such as separators, electrolytes, cathode, and anode material. It will show how production geographic concentration and potential new trends in other regions.
   a) *Cell Manufacturing:* studies on battery cells assembling by the production of electrodes will be undertaken to explore the supremacy of Asian countries, mainly China, in cell manufacture. Strategic alliances and investments will be part of review.
3) Downstream Stage:
   b) *Battery pack assembly:* The assembly of LIB cells into battery packs will be studied, with particular attention to quality assurance and testing. The significance of prismatic cells in automotive usage will be discussed.
   c) *Battery Recycling End-of-Life:* The study will analyze the processes of recycling such as pyrometallurgy, hydrometallurgy, and direct recycling and their levels of market shares and will highlight the dominance of China in the segment of recycling. The analysis will cover policy mandates, extended producer responsibility (EPR), and joint ventures between original equipment manufacturers (OEMs) and recyclers.

The value chain analysis in this study would illuminate the lithium-ion battery value chain analysis in three aspects: upstream, midstream, and downstream. The objective of this study is to explore the structure and dynamics of the industry at a micro level, to identify potential sources of competitive advantage and areas for improvement and also to explore strategic options for Ethiopia to promote its competitiveness in the global LIB industry through analyzing the main activities, players and the dynamics in each phase of the value chain. This would enable the findings to contribute to a strategic roadmap for Ethiopia's engagement in the lithium-ion battery value chain to achieve sustainable economic growth and aid the global shift towards electric mobility and sustainable energy solutions.

3. Research Methodology

3.1. Research Design

In this study, qualitative as well as quantitative methods were applied with the mixed-method research design. The conceptual framework of the study incorporated:

Global Value Chain Mapping: Based on a set of existing LIB value chain maps elaborated in [6] and [14] identifying main stages, key actors, and governments.

Focused Group Discussions: An eight-member expert panel was held consisting of:

1) Ministry of Mines (2 experts)
2) Geology Institute of Ethiopia (2 experts)
3) Minerals Industry Development Institute (2 experts)
4) Manufacturing Technology and Engineering Industry Research and Development Centre (2 experts)

The discussions were held on May 16 and 23, 2023 in the Ministry of Mines based on structured discussion guides that focused on all aspects of Ethiopia's LIB potentials and capabilities.

SWOT Analysis of Ethiopia's Strengths, Weaknesses, Opportunities and Threats at Upstream, Midstream and Downstream of the LIB value chain.

Porter's Five Forces Analysis: Analysis of Industry competitive structure to the extent of new entry, buyer power, supplier power, threat of substitutes and industry competitors.

3.2. Data Collection

Primary Data: A set of focused group discussions was conducted with the customers and experts. Secondary Data: Retrieved from peer-reviewed journals, industry reports (IEA, Bloomberg NEF, USGS), financial databases and government reports (2014-2030).

3.3. Assumptions and Limitations

3.3.1. Assumptions

This research is based on

1) The assumptions that LIBs will continue to be the leading technology of EV energy storage
2) Worldwide EV penetration will increase as forecasted,
3) The Ethiopian policies will continue to be supportive,
4) Necessary investment capital can be attracted, and
5) The international collaboration on clean energy supply chains will continue.

3.3.2. Limitations

1) Lack of Data: The study may be constrained by limited

data on Ethiopia's mineral reserves.

2) Market Dynamics: The LIB market is subject to rapid technological and economic changes.
3) Stakeholder Perspectives: Insights from key stakeholders, such as policymakers and investors, may not be fully captured.
4) External Dependencies: Global economic conditions and geopolitical factors influencing the value chain are not thoroughly examined.

Interpretations should consider these limitations, and further research is recommended to address any gaps.

3.4. Ethical Considerations

Written informed consent was obtained from all the subjects. The confidentiality of the data was guaranteed by means of safe storage and restricted access. All secondary sources were appropriately credited and results were presented objectively and without any bias towards a particular group of stakeholders.

4. Results and Discussion

4.1. Ethiopia's Mineral Resources for LIB Production

Comprehensive assessment of Ethiopia's mineral reserves reveals significant potential for LIB value chain participation (Table 2).

Table 3. *Ethiopia's Main Reserves Related to Lithium-Ion Batteries (LIBs).*

The type of mineral	Amount of stock that has been studied in	Location/Remark
Copper	50,000,000 tons	✓ 8587 tons of proven reserves have been issued to the Company for production;
Lithium	419,116 tons	✓ From Kenticha granites-pegmatite ✓ Requires detailed study
Nickel	17,000,000 tons	✓ Although there are conditions indicating the existence of the mineral in different places, it needs further research;
Manganese	Not quantified	✓ Even if there is no quantitative information, there are conditions indicating the existence of the mineral in different places, so it needs further research.
Phosphate	181,000,000 tons	✓ Apart from this, although the size of the stockpile has not been disclosed, it is assumed that there is a wide range of resources, so it requires further research.
Graphite	460,000 tons	✓ Although the size of the stockpile has not been disclosed, it is believed to be extensive and requires further study.

Source: Ministry of Mines, 2023

Furthermore, geological studies in the Danakil Depression corroborate the presence of lithium in brines related to potash layers, with a lithium concentration of about 3 million tons in 50% recovery [7]. This places Ethiopia among the six African countries with high lithium content that China targeted for strategic partnership [12].

From group discussions: Group discussions suggest that Ethiopia now has the following constraints in competing with experienced actors of LIB cell production:

1) Limited Infrastructure and Technology Gap
2) Restrictive Access to Critical Raw Materials on Commercial Level
3) Lack of Economies of Scale
4) Weak Supply Chain Integration.

But there may be room to expand in battery making and parts assembly with Ethiopia’s burgeoning electronics manufacturing know-how, labor force and investment-friendly terms. The automobile industry has many entry barriers that need strategic collaborations and investments.

4.2. SWOT Analysis of Ethiopia's Engagement in the LIB Value Chain

SWOT analysis insights were the Ethiopia's potential and capabilities in LIB value chain Utilizing SWOT analysis, the study provided valuable insights into Ethiopia's strengths, weaknesses, opportunities, and threats concerning its potential and capabilities within the LIBs value chain. The expert team developed comprehensive evaluation criteria for each stage in the value chain and conducted a thorough assessment of Ethiopia's competitiveness. It identifies the main challenges and success factors of each stage of the lithium-ion cell value chain, and evaluated the main players in terms of production capacity and experience and other factors.

These studies highlight the various regions' potential and opportunities to participate in the lithium-ion battery value chain, ranging from mineral extraction to cell manufacturing and recycling. Each region's unique strengths and resources can contribute to the growth and development of the global battery market and electric vehicle industry.

Table 4. SWOT Analysis Across the LIB Value Chain.

Upstream Stage	**Midstream Stage**	**Downstream Stage**
Mining & Raw Material Extraction	Processing & Manufacturing	Battery Assembly & EV Market
Strengths 1) Abundant lithium resources 2) Low-cost raw material extraction 3) Early entry potential	Strengths 1) Access to renewable energy 2) Youth labor force 3) Industrial development	Strengths 1) Growing EV demand 2) Sustainable transition
Opportunities 1) Job creation & growth 2) Rising global demand 3) Simple extraction tech 4) High value potential	Opportunities 1) Local value addition 2) Technology transfer 3) Battery materials	Opportunities 1) Export potential 2) Renewable integration 3) Regional markets
Weaknesses 1) Limited infrastructure 2) Logistical challenges	Weaknesses 1) Weak infrastructure 2) Skills shortage 3) Supply chain gaps 4) High costs	Weaknesses 1) Small market size 2) Tech complexity 3) High capital needs
Threats 1) Global competition 2) Market demand variability	Threats 1) Intense global competition 2) Rapid technological upgradation	Threats 1) Global competition 2) Market demand variability
Competitive Advantage: HIGH	Competitive Advantage: LOW	Competitive Advantage: LOW

4.3. Competitive Advantage Assessment

The SWOT analysis shows that Ethiopia's strongest competitiveness in the LIB value chain is found in the upstream stage, with traits such as:

1) Producer-driven markets allowed influencing to the prices of raw material
2) Bargaining Power of Suppliers: the potential supplier of lithium has a strong bargaining power
3) Lower barriers to entry because of accessibility to brine deposits
4) Opportunities to create value (as much as 80% of the value from ore to refined metal salts)

Competitive advantage is weak in the midstream and downstream stages, where the technology is complex, capital-intensive and dominated by established global competitors.

Ethiopia's Current Position in the Global LIB Value Chain

The result of the FGD suggests that the participation of Ethiopia in the lithium-ion battery (LIB) value chain is nonexistent at a time when it has no means of competing with the established ones in LIB cell production because of;

1) Limited infrastructure and technological gaps
2) Restricted access to key raw materials at commercial scale
3) Absence of economies of scale
4) Underdeveloped supply chain integration

However, opportunities exist in battery manufacturing and component production, leveraging Ethiopia's growing expertise in electronics manufacturing, skilled labor force, and favorable investment incentives. The automotive sector presents significant entry barriers requiring strategic investments and partnerships.

4.4. Porter's Five Forces Framework

It provides a useful tool for analyzing the competitive dynamics and potential competitive advantage of a country or industry. In the case of Ethiopia's potential participation in the raw material extraction and processing segment of the LIBs value chain, the framework can shed light on the country's competitive position.

***Table 5**. Summarization of Porter's Five Forces analysis.*

Porter's Five Forces framework	Description
Threat of New Entrants	✓ The threat of new entrants to Ethiopia's involvement in the upstream stage is relatively low, considering its potential access to brine deposits for lithium extraction.
Bargaining Power of Suppliers	✓ Ethiopia's potential access to brine deposits containing lithium gives it a strategic advantage as a supplier, potentially enhancing its bargaining power in the global LIBs market.
Bargaining Power of Buyers	✓ Ethiopia can leverage its potential as a lithium supplier to negotiate favourable terms with buyers, but it needs to ensure a competitive advantage in terms of quality, cost-effectiveness, and sustainability.
Threat of Substitutes	✓ The threat of substitutes in the upstream stage is currently low, as lithium-ion batteries are the dominant energy storage solution. Ethiopia should monitor market trends, invest in R&D, and adapt to emerging technologies to mitigate future threats.
Competitive Rivalry	✓ Competition in the upstream stage exists among countries with access to critical materials. Ethiopia's potential access to brine deposits provides a competitive advantage, but it should focus on sustainable practices, strong supply chains, and reliability to differentiate itself.

According to Porter's Five Forces analysis, Ethiopia has promising opportunities in the upstream stage of the lithium-ion battery (LIB) value chain due to potential access to brine reserves. By focusing on cost-effectiveness, reliability, and sustainability, Ethiopia can position itself as a market leader. Investing in research and development (R&D) and closely monitoring market trends will further enable Ethiopia to respond to emerging trends and solidify its position in the industry.

Study focusing on South Africa suggests that the country has opportunities for developing the lithium-ion battery manufacturing value chain. Mineral refining and battery production in South Africa are ready for scaling up. The study also mentions that the economic viability of cell production and recycling will be further investigated in the medium to long term [16].

4.5. Discussion

The focus group discussion gave some good insights on the opportunities and challenges for Ethiopia in the lithium-ion battery (LIB) value chain. The discussion was also enriched by the diverse insights and expertise of the participants, covering key topics such as the availability of mineral resources, capacity to manufacture, policy frameworks, sustainability considerations, international cooperation and workforce development.

These findings indicate that although Ethiopia is currently facing substantial barriers to achieving direct competition with mature global LIB manufacturing centers it has a few unique regional advantages that could be capitalized on strategically. Part of Ethiopia's strengths lies in its large lithium brine resources, the possibility of running industrial production on plentiful renewable energy, and its geographical position, which would open doors to both regional and international markets. However, the strengths are counterweighed by significant weaknesses including lack of industry infrastructure, limited technological capabilities, and dearth of highly trained labor in high volume battery production.

Yet, there are also some prospects for Ethiopia to enhance its position in the LIB value chain. These comprise foreign direct investment (FDI), the formation of international alliances to facilitate technology transfer, and penetration in nascent regional markets with accelerating demand for electric mobility and energy storage. However, Ethiopia also needs to preempt potential threats, for example intense global competition, rapidly evolving technology in leader countries, and regulatory or institutional barriers that may influence industry development.

SWOT analysis presents a number of elements that needed to be addressed strategically. For example, utilizing Ethiopia's renewable energy potential could be a sustainable and cost-effective energy source for LIB related industries. Furthermore, focused policy changes and infrastructure investment might dramatically raise the country's appeal to investors. It will also be vital to enhance cooperation with other nations to ensure a smooth transfer of technology, knowledge, and capacity building.

In this context, a set of operational recommendations is presented to take up these strengths and to mitigate the weaknesses. Combining the outcomes of the focus group discussion, SWOT analysis and Porter's Five Forces, Ethiopia is likely to formulate realistic option to strategically engage and grow in the global LIB value chain.

4.6. Strategic Framework: Ethiopia's Lithium-Ion Battery Value Chain Integration

The strategic path involves an active multi-pronged approach towards converging on end state for systematically improving Ethiopia's competitive standing in the global lithium-ion battery (LIB) value chain, leveraging existing national competitive advantages, rectifying structural weaknesses, and applying buffer against external threats. The holistic strategy involves a staged realization based on a short-term solid foundation for building up capacity in the mid-term and achieving industrial leadership in the long-term in order to advance domestic competence in lithium recovery, critical material refining and LIB component production.

Strategic Objectives

Achieve Sustainable Competitive Advantage

Optimization of mineral resources

1) Develop cost-effective, scalable lithium and co-located critical mineral (cobalt, nickel, graphite where geologically feasible) extraction and processing methodologies and operations.
2) Use state of the art exploration methods to fully delineate/quantify national mineral reserves.
3) Build integrated mine-to-refined-material supply chains to eliminate value leakage.

Environmental Stewardship & Social Responsibility

1) To initiate world-class sustainable mining operation beyond international environmental norms.
2) Formulate all-encompassing environmental protection measures which include water preservation, land restoration and carbon emission reduction.
3) Institute community participation mechanisms for sharing benefits and creating local ownership and social license to operate.
4) Make Ethiopia a preferred “green” supplier to battery manufacturers and EV companies that are earth friendly."

Downstream Industrial Development

1) Develop strong refining capacity that is able to produce battery-grade lithium carbonate and lithium hydroxide
2) Attract and nurture cell component suppliers (cathode and anode materials, electrolytes, separators)
3) Establish specialized industrial parks with common infrastructure to lower entry barriers for parts suppliers
4) Promote technology-transfer collaboration with established international leaders for rapid scaling of capabilities

Table 6. *Strategic Stakeholders and Activities with Timelines.*

Stakeholder	Short-Term Goal (Lithium Extraction)	Mid-Term Goal (Critical Materials Development)	Long-Term Goal (Manufacturing and Refining)
Universities and Research Institutions	1) Conduct research on lithium-ion battery (LIB) technologies and materials in collaboration with universities, research centres, and international partners. 2) Support resource assessment and early-stage R&D on lithium brines and related minerals.	1) Establish academic programs and technical training in extractive metallurgy, battery technology, and mineral processing. 2) Strengthen technical education and workforce development through collaboration with colleges, technical schools, and training centres. 3) Enhance practical technical skills through specialized programs and institutional capacity building.	1) Collaborate with industry partners to address skills shortages in advanced battery manufacturing. 2) Promote innovation, research, development, demonstration, and commercialization through partnerships with leading global research institutions and manufacturers.
Government Agencies	Conduct comprehensive evaluations of Ethiopia’s lithium brine resources to determine their quantity, quality, and economic viability.	1) Streamline licensing procedures and provide fiscal incentives to attract investment into the upstream LIB value chain. 2) Strengthen regulatory frameworks to support responsible resource development.	1) Enforce strong environmental standards and monitoring systems. 2) Promote value-added processing and industrial development within the battery sector.
Supportive / Enabling Institutions	mprove infrastructure required for mineral extraction and transportation, including roads, energy supply, and logistics networks.	Expand infrastructure capacity to support the extraction and transportation of other critical battery minerals such as graphite, nickel, and	Establish refining and processing facilities to convert raw materials into battery-grade products that meet international standards.

Stakeholder	Short-Term Goal (Lithium Extraction)	Mid-Term Goal (Critical Materials Development)	Long-Term Goal (Manufacturing and Refining)
		cobalt.	
Investors and Private Sector	Invest in mining infrastructure and the extraction of lithium brines.	Invest in the development and supply of critical battery materials such as cobalt, graphite, and nickel.	Invest in battery manufacturing facilities and component production to strengthen domestic manufacturing capabilities.

By adhering to this strategic framework, Ethiopia aims to establish itself as a significant player in the global lithium-ion battery (LIB) market. This involvement will not only support the global transition to clean energy but also foster sustainable economic growth within the country. Through targeted investments, innovation, and leveraging its natural resources, Ethiopia envisions creating a robust and competitive presence in the LIB industry, contributing to both environmental sustainability and economic development.

5. Conclusion and Recommendation

5.1. Conclusion

This is the first study to assess the competitiveness of Ethiopia in the global lithium-ion battery value chain. Findings include the following:

1) Resource Availability: Ethiopia has abundant mineral resources is necessary for LIB production, the Danakil Depression holds about 3 million tons of lithium brines along with reserves of nickel (17 million tons) and graphite etc. Extraction of lithium brines is more competitive owing to less complexity of infrastructure and lesser requirement of capital.
2) Competitiveness: Ethiopia has the highest degree of competitiveness in the upstream phase, it is raw material price sensitive and raw material suppliers are holding high bargaining power in this producer-driven industry. Technology complexity and capital intensity impose steep barriers to midstream and downstream entry, recognizing fierce competition globally from China, South Korea, Japan, and Western countries.
3) Ethiopia In: Ethiopia has no proven LIB industry development strategy at present, and is faced with limited infrastructure and technological gaps, as well as fragmented supply-chain.
4) Conclusion Plan: The proposed multi-stage approach including short-term (lithium extraction), medium-term (other critical minerals) and long-term (manufacturing and refining) perspectives acts as a guideline to improve the competitiveness of Ethiopia and to best extract benefits from novel LIB value chain-engagement.
5) Enabling Conditions: Ethiopia has abundant potential renewable energy (hydropower in particular), capable of powering energy intensive midstream activities, a young labor force, promising opportunities for skills development in cutting-edge industries with high innovation content.

5.2. Recommendation

For Policymakers:

1) Investment First: To take advantage of the Ethiopians' competitive advantage in the upstream level, focus on investment in extraction of lithium from brine deposits.
2) Enforcement of Legislation: Establish a clear, transparent mining code that enables ethical mining, environmental conservation, and a fair share of the gains. Streamline the permit application process and provide incentives for mining investment.
3) Infrastructure Investment: Finance transportation, energy, and processing infrastructure that enables the efficient extraction and refining of critical minerals.
4) International Collaborations: Promote cooperation and joint ventures with existing LIB producers for technology transfer, knowledge sharing, and capacity building at the midstream and downstream stages.
5) Certification Centers: Put in place certification and testing centers for LIBs in order to comply with international standards and increase access to markets.

For Industry players:

1) Value Addition: Emphasize local value addition investments in midstream processing that yields greater-value battery materials and intermediate products.
2) Capacity Building: Support workforce education and training initiatives to develop expertise in LIB technologies, manufacturing procedures, and quality assurance.
3) Research and Development: Investigate to innovate and improve extraction technology and processing techniques to decrease costs and increase productivity.
4) Sustainable Practices: Implement sustainable and environmentally responsible practices for mining and processing to improve branding and portfolio of responsible investors.

For Investors:

1) Strategic Footing: Initial investments should target the

concentration of lithium given Ethiopia's comparative advantage in this area.
2) Partnership Building: Forge alliances with Ethiopian universities and institutions and/or global players to enable technology transfer, and access markets.
3) Long-term Commitment: Consider phased investments aligned with the strategic framework, progressing from extraction to processing and eventually manufacturing.

6. Future Research Directions

1) Technological Advancements: Investigate emerging LIB technologies (solid-state batteries, alternative chemistries) and their implications for Ethiopia's resource development strategy.
2) Sustainable Supply Chain: Develop methodologies for sustainable and responsible sourcing of LIB materials, including environmental and social impact assessments.
3) Market Dynamics: Conduct detailed demand forecasting for LIB products across various sectors (EVs, consumer electronics, renewable energy storage) to identify optimal market niches.
4) Environmental Impact Assessment: Perform comprehensive analysis of environmental effects associated with LIB production, consumption, and disposal in Ethiopia, developing strategies for mitigation.
5) Economic Modeling: Develop economic models to assess the viability of different value chain participation scenarios, considering global price fluctuations, technology evolution, and policy changes.

7. A Data Availability Declaration

The data that support this study are from two sources:

Primary Data: A panel discussion with 8 experts from the Ministry of Mines, Geology Institute of Ethiopia, Minerals Industry Development Institute, Manufacturing Technology and Engineering Industry Research and Development Center, held on May 16 and 23 2023. The raw transcripts and individual responses are treated as confidential information and are not made publicly available to protect the privacy of participants.

Secondary Data: Cited publicly available sources including IEA, USGS, Bloomberg NEF, ITC Trade Map, academic literature and publications of the Ethiopian government.

Mineral Resource Calculations: Danakil (3 Mt at 50% recovery) lithium estimates are taken from [7] and preliminary Ministry of mines data (2023) and illustrate geological potential, not defined commercial reserves in accordance with international standards (JORC/NI 43-101).

Resulting Data: All the analyses (SWOT matrices, Five Forces evaluations, strategic frameworks) are completely reported and thus reproducible in the manuscript. Sopa believes that detailed exploration data held by the Ministry of Mines are confidential and cannot be shared publicly. Requests for additional information should be sent to the corresponding author.

Abbreviations

LIB	Lithium-ion Battery
AfCFTA	African Continental Free Trade Area
DRC	Democratic Republic of the Congo
AI	Artificial Intelligence
BMS	Battery Management System
ERBI	Equitable Resource-Based Industrialization
IEA	International Energy Agency
EPR	Extended Producer Responsibility
OEMs	Original Equipment Manufacturers
EV	Electric Vehicle
R&D	Research and Development
FDI	Foreign Direct Investment
Mt	Metric Ton (or Metric Tonne)
Bloomberg NEF (BNEF)	Bloomberg New Energy Finance
USGS	United States Geological Survey
JORC	Joint Ore Reserves Committee
NI 43-101	National Instrument 43-101 (Canadian Standard for Disclosure of Mineral Projects)
LiPF6	Lithium Hexafluorophosphate.
Li_2CO_3	Lithium Carbonate
LiOH	Lithium Hydroxide
LiCl	Lithium Chloride
SWOT	Strength. Weakness, Opportunity, Threat
FGD	Focused Group Discussion
ITC	International Trade Centre

Author Contributions

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Conflicts of Interest

The authors declare no conflicts of interest.

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