University of Windsor

COMP8790 - Topics in Applied AI

Literature Review (Project A)

Modeling Sustainable Solutions for Lithium Mining Impact Reduction

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1 Introduction

Lithium is very useful for storing electricity such as batteries now is being called white gold. There is a reason for that, the number of Electric Vehicles is being produced by many big car companies, and they need lithium and there are only a few places that have lithium as a mineral. Lithium, a key component in clean energy technologies, faces a rising demand [27] alongside environmental concerns from mining. Water depletion, ecosystem disruption, and land degradation [28] highlight the need for sustainable solutions. Given these impacts, it is imperative to explore sustainable mining practices and innovative technologies that can reduce the environmental footprint of lithium extraction. Modeling approaches, like agent-based models (ABMs) and Life Cycle Assessments (LCAs), can simulate complex interactions and assess environmental impact. This review explores existing research on how these models are used to analyze current practices, evaluate new technologies, and design mitigation strategies. By identifying strengths, limitations, and knowledge gaps, this review aims to guide future modeling efforts toward a sustainable future for lithium mining.

Our approach is to see how all these emergent behaviours affect the local community, environment, and economic growth of the community by using agent-based modeling. The goal is to build an agent-based simulation to gain insight into this complex system to make better policy decisions to save the environment and the people around that area. In our simulation, agents will interact with each other and will be heterogeneous. Agent-based modelling (ABM) is a potent computational technique that is used to model how agents—individual entities like people, businesses, or machines interact with one another in a particular environment to evaluate how those interactions affect the system. ABM can be used in the context of lithium mining to evaluate and forecast the actions and results of numerous mining-related aspects, including:

Environmental Impact: The effects of various mining techniques on the natural world.
Economic Factors: How mining operations are affected by supply, demand, and market prices.
Social Impact: The results on labour forces and nearby communities.

2 Literature Review

1. **Title: Sustainable phosphate mining: Enhancing efficiency in mining and pre-beneficiation processes**

The authors addressed the issue of residual phosphate presence in waste stocks throughout the phosphate mining and pre-beneficiation processes impacting the environment [1].

The authors used system dynamics simulation of AnyLogic software to simulate different scenarios (base case, extraction phase, pre-beneficiation phase, old spoil piles, integrated Approach) for recovering and preventing residual phosphate and evaluate the impact of proposed scenarios on phosphate recovery and waste reduction. They used data from a Moroccan mining site, recent literature, and information from a lithological log. They focused on extraction, destoning, and screening processes to identify stages where residual phosphate exists. They used agents representing different stages of the extraction process, waste products generated during mining and pre-beneficiation, various forms of phosphate products and their respective grades, and pre-beneficiation processes designed to recover phosphate from waste streams. They identified three primary stages where residual phosphate exists and simulated various recovery and prevention scenarios and conducted detailed analyses of the phosphate extraction, crushing, and sieving processes [1].

The simulation revealed that 76% of the phosphate resource is recovered, with significant portions found in destoning waste rocks and screening waste rocks. The simulation also suggested a potential 25% increase in total phosphate resource recovery and a twofold increase in storage by implementing the proposed scenarios. The methodologies and findings from this study can be applied to lithium mining to enhance recovery processes, reduce waste, and improve overall sustainability. Any logic system dynamics simulation can be used to optimize lithium extraction and processing, ensuring that more of the valuable resource is recovered and less is wasted, thereby mitigating environmental damage [1].

2. Title: Life cycle environmental impacts of current and future battery-grade lithium supply from brine and spodumene Mudit Chordia *, Sanna Wickerts, Anders Nordelof, ¨ Rickard Arvi

The authors addressed lithium production's environmental impact, analyzing current and future sources derived from brine and spodumene across their entire life cycle.

The authors utilized the life cycle assessment (LCA), which covered multiple impact categories including climate change, water use, freshwater ecotoxicity, and mineral resource scarcity to evaluate the environmental impacts of lithium production. The assessment focused on the cradle-to-gate impacts, from raw material extraction to the production of battery-grade lithium hydroxide monohydrate. The authors reviewed data from the Ecoinvent database, scientific literature, and technical reports from upcoming production facilities and modeled the production processes for lithium hydroxide from these sources, including brine extraction, concentration, and chemical processing, as well as spodumene mining, concentration, and chemical processing. The impacts were assessed using specific unit processes for each stage, and background data was sourced from the Ecoinvent v3.8 database [2].

The study highlighted that hydroxide monohydrate production might contribute 5-15% to the overall climate change effects from large-scale LIB production facilities. These impacts are generally higher when hydroxide monohydrate is produced from lower-grade brine sources present in Cauchari and Maricunga compared to higher-grade sources present in Atacama, as higher energy and chemical requirements needed to process larger volumes of brine with lower lithium concentrations. For spodumene-based lithium, Australian sources show higher climate impacts because of their dependence on carbon-intensive energy sources. The processing of ore and management of tailings generally affected freshwater ecotoxicity, alongside the mining and processing of sulfidic ores and the treatment of hard coal ash. The study also highlighted that brine-based lithium production has a higher impact on mineral resource scarcity because of the extraction of other dissolved substances such as chlorine, boron, and magnesium. The spodumene-based processes, combined with the high volumes of brine water evaporated during extraction, lead to potential pressure drawdowns and the risk of freshwater infiltrating into brine aquifers [2].

For further research, the authors suggested improving the accuracy and representation of data related to lithium extraction processes. They also suggested developing a new life cycle impact assessment method to address the complexities of hydrological cycles in lithium brine extraction areas and considering the potential for secondary lithium sources through recycling to reduce environmental impacts [2].

3. Title: Lithium in the Green Energy Transition: The Quest for Both Sustainability and Security

The authors addressed the consequences of rising global lithium demand, crucial for batteries in electric vehicles (EVs) and grid-scale energy storage. The authors examined the sustainability and energy security risks associated with heavy reliance on lithium, considering China's control over the lithium supply chain and the challenges in expanding lithium mining in areas such as Chile, the United States, and Europe. [3].

The study involved the review of existing literature on lithium extraction, processing, and its socio-environmental consequences. The authors used data from various sources, such as industry reports, government documents, and academic research, to provide an in-depth analysis of the global lithium market and its challenges [3].

Although lithium resources are abundant globally, with significant reserves in countries like Chile, Argentina, Bolivia, and Australia, mining and processing these resources have many challenges. In Chile, environmental issues and conflicts between mining companies and the government have slowed production, with new projects facing opposition from Indigenous groups and environmentalists due to water consumption and habitat disruption. In the United States, lithium mining is seeing a revival, but it faces environmental and social challenges. Projects like Piedmont Lithium in North Carolina and Silver Peak Mine in Nevada highlight difficulties in improving domestic production. China imports over 80% of its lithium, while Australia leads global lithium production due to its strong mining infrastructure, supportive policies, and significant foreign investment [3].

The authors highlighted that significant socio-environmental impacts of lithium mining include water scarcity, local opposition, and life cycle issues. They suggested various strategies to mitigate these adverse effects, such as direct lithium extraction, recycling and reuse, and the use of alternative batteries [3].

4. Title: Potential environmental impacts of lithium mining

The author discussed the increasing environmental concerns from intensified lithium mining activities, driven by the rising demand for lithium-ion batteries used in electric vehicles and electronics [4].

The author presents an in-depth review of lithium mining processes, including both brine and hard rock extraction methods. By analyzing existing literature and data on lithium mining worldwide, the author discusses the technical and environmental challenges of each method by specifically examining major lithium-producing regions, lithium triangle situated in South America, and evaluates the technological and environmental impacts of current mining practices through a life-cycle assessment lens.
Lithium mining is divided into extraction and processing phases, utilizing different methods for brine and solid rock sources. The extraction of lithium, especially from brines, demands huge water consumption as it might lead to significant water loss of up to 95%, resulting in nearby water resource depletion and can also impact the local geography and infrastructure, potentially causing land subsidence. Toxic chemicals used in processing lithium can contaminate water supplies, soil, and air [4].

To mitigate the environmental effects of lithium mining, the author discussed various technologies. These include enhancing water management techniques for recycling and reusing water during mining, using materials that selectively adsorb lithium, and reducing dependency on large evaporation ponds. The use of ionic exchange columns and chromatography to concentrate lithium more efficiently and with less environmental harm, and the use of electrolysis to selectively capture lithium ions, which is more eco-friendly compared to traditional methods [4].

The author highlighted the need for improved regulations, better data on environmental impacts, and the adoption of alternative technologies to minimize the adverse effects of lithium extraction and processing as lithium-ion batteries are crucial for reducing carbon footprints [4].

5. Title: Life cycle assessment of lithium-ion battery recycling using pyrometallurgical technologies

This study evaluates the environmental and energy impacts of three pyrometallurgical recycling technologies, Direct Current (DC) Plasma Smelting, DC Plasma Smelting with Pre-treatment and Ultra-High Temperature (UHT) Furnace, for used lithium-ion batteries (LIBs) from electric vehicles.
The study employs a Life Cycle Assessment (LCA) methodology to analyze and compare the global warming potential (GWP) and cumulative energy demand (CED) of the three pyrometallurgical technologies. The LCA considers both “open-loop” and “closed-loop” recycling options to assess the environmental impacts of recovering metals from spent LIBs [5].

The authors use the cradle-to-grave Life Cycle Assessment approach to analyze and compare the global warming potential (GWP) and cumulative energy demand (CED) of the three pyrometallurgical technologies. LCA includes the pyrometallurgical processing stage and the subsequent hydrometallurgical stage required to recover valuable metals from the resultant alloy. The authors considered both open-loop and closed-loop recycling options to assess the environmental impacts of recovering metals from used lithium-ion batteries. The LCA models for the three pyrometallurgical technologies were constructed using the Umberto LCA+ Software package and one tonne of LIB modules were treated using these models. The authors excluded the collection, transportation, discharging, and dismantling of batteries and focused mainly on the pyrometallurgical and hydrometallurgical stages as model system boundaries [5].

The experiment revealed DC plasma with pre-treatment showed the lowest GWP, followed by DC plasma and then UHT furnace. There could be a decrease in GWP by a factor of 5 after shifting from the UHT furnace to DC plasma with pre-treatment. In closed-loop recycling and open-loop recycling DC plasma with pre-treatment performed better as well as showed higher efficiency in recovering valuable metals than the other two [5].

The results highlighted the significance of an upgrading phase in the recycling procedure and suggested that commercial upgrading techniques should be cost-effective and effectively remove materials from LIBs before furnace processing [5].

6. Title: Current and Future Global Lithium Production

Introduction: Overview and Approach
The global lithium market has seen substantial growth, driven primarily by the increasing demand for lithium-ionAs of 2023, a market valued at USD 31.75 billion, composed of batteries utilized in electric vehicles (EVs) and energy storage solutions, is anticipated to experience a compound annual growth rate (CAGR) of 17.7% from 2024 to 2030. This growth is fueled by regulatory pressures on automotive emissions, prompting a shift towards EV production. Technological advancements like the emergence of

solid-state batteries and the integration of lithium in renewable energy storage systems have significantly driven market expansion. This section introduces the lithium market dynamics, emphasizing the role of these technological advancements and government initiatives in driving market expansion.
Summary of Research Paper

"Chart: Which Countries Produce the Most Lithium?"
This paper from the World Economic Forum provides an in-depth analysis of global lithium production, highlighting key players and emerging trends. The major lithium producers, namely Australia, Chile, and China, dominate the market, collectively accounting for over 80% of the global supply. Australia leads with its hard rock spodumene resources, while Chile exploits vast brine deposits in the Atacama Desert. China not only produces lithium but also controls a significant portion of the battery manufacturing supply chain. Emerging producers like Argentina and Bolivia are also noted for their large reserves and potential future contributions. The paper discusses the environmental and economic impacts of lithium extraction, emphasizing the need for sustainable practices to address environmental concerns such as water usage, ecosystem disruption, and the economic benefits and challenges of lithium production.

"Breaking Down the Cost of an EV Battery Cell"
This article, published by Visual Capitalist, explores the economic aspects of lithium and its impact on the cost of EV batteries. It details how lithium prices have dropped significantly over the past year, making investments in lithium more attractive. The cost of lithium-ion batteries has decreased as a result of increased production scale and advancements in technology. The paper underscores the importance of lithium in the clean energy transition and the sustained adoption of EVs. It notes that EVs have reached 'price parity' with traditional vehicles, meaning that the total cost of ownership, including fuel and maintenance, is now comparable. This development further drives demand for lithium.

Conclusion

The literature on lithium production highlights the critical role of key producing countries in meeting the escalating demand driven by the global transition to renewable energy and electric mobility. The primary producers, Australia, Chile, and China are pivotal in supplying the world's lithium needs. Moreover, emerging markets like Argentina and Bolivia, with their large reserves and potential future contributions, offer a promising outlook. The current approaches to lithium extraction and production are geared towards scaling up supply to meet future demands. However, these methods face limitations such as lengthy project development timelines, environmental impacts, and the need for sustainable mining practices. Addressing these challenges through innovation and sustainable practices is crucial for ensuring a stable and environmentally responsible lithium supply chain. Future research and simulations should focus on optimizing extraction techniques, minimizing environmental impacts, and exploring alternative sources and recycling methods to enhance lithium supply sustainability.

7. Title: Lithium Market Size, Share & Trends Analysis Report By Product (Carbonate, Hydroxide), By Application (Automotive, Consumer Goods, Grid Storage), By Region, And Segment Forecasts, 2024 – 2030

Introduction

The global shift towards renewable energy and electric mobility, a movement in which you, as researchers, policymakers, and industry professionals, play a crucial role, has dramatically boosted the demand for lithium, an essential element in lithium-ion batteries used in electric vehicles (EVs) and various electronic devices. As the world endeavours to mitigate climate change and reduce its reliance on fossil fuels, your understanding of the dynamics of lithium production becomes essential. This paper delves into the geographical distribution of lithium production, spotlighting the leading countries in this industry and the challenges and opportunities that arise as the world becomes more dependent on lithium for its energy needs.

Summarization of Research Paper

The detailed summaries of the research papers related to the lithium market can be structured as follows, given the comprehensive nature of the provided material:

Lithium Market Size & Trends

The global lithium market is on the brink of a significant growth phase, with projections indicating a robust CAGR of 17.7% from 2024 to 2030. This promising trajectory is driven by the surge in EV adoption, facilitated by government incentives and regulatory frameworks aimed at reducing carbon emissions. The automotive sector, particularly in regions like the U.S. and China, stands out as a major consumer, contributing to the market's expansion.

Government Initiatives & Market Impact

Government subsidies and investments play a pivotal role in accelerating market growth. The designation of lithium as a critical mineral in the U.S., a classification that highlights the mineral's importance to the country's economy and national security, underscores its strategic importance. This designation has led to expedited mine permitting processes and increased government support for lithium mining projects. Initiatives like the Thacker Pass Lithium Mine are expected to bolster domestic supply, thereby enhancing the country's position in the global lithium market.

Price Trends & Market Dynamics

Lithium prices have exhibited volatility, experiencing significant increases followed by declines due to supply-demand imbalances. Factors contributing to this volatility include the unpredictability of EV adoption rates, changes in government policies, and the pace of new lithium production capacity coming online. Despite supply expansions, demand has not met initial expectations, leading to surplus conditions. Regulatory scrutiny and operational adjustments in major producing countries like Australia have also influenced market dynamics, impacting price trajectories and production strategies.

Market Concentration & Innovation

The lithium market is characterized by consolidation, with major players harnessing the power of innovation to optimize production processes and meet the growing demand. Research and development efforts are laser-focused on enhancing battery technologies, particularly for EV applications. Regulatory compliance and end-user proximity drive manufacturing decisions, supporting market competitiveness and sustainability.

Product & Application Insights

Lithium carbonate dominates the market, serving as a versatile compound in various applications, including batteries and pharmaceuticals. The automotive and consumer electronics sectors drive demand for lithium products, with rechargeable batteries witnessing widespread adoption across diverse industries. Developments in energy storage systems further underscore lithium's pivotal role in advancing technological innovations.

Regional Insights & Market Dynamics

Regional dynamics highlight North America's significant role in lithium consumption. This role is driven by several factors, including the region's strong demand for EVs, regulatory support for clean energy transitions, and the designation of lithium as a critical mineral. These factors have led to the establishment of several lithium mining projects in the region, contributing to its position as a major consumer in the global lithium market. Asia Pacific remains the largest market, propelled by industrial growth in the automotive and consumer electronics sectors, particularly in China and Japan. Europe and Central & South America also show promising growth trajectories, supported by increasing EV adoption and resource investments.

Conclusion: Insights and Future Directions

In conclusion, the literature on the lithium market underscores its rapid expansion driven by EV proliferation and technological advancements. While the market is full of growth opportunities, it's important to acknowledge the challenges such as price volatility and supply chain dependencies that remain pertinent. Future research and simulations will focus on addressing these challenges, particularly in optimizing supply chain resilience and enhancing sustainability practices across the lithium value chain.

8. Title: Estimating the environmental impacts of global lithium-ion battery supply chain: A temporal, geographical, and technological perspective

Research Paper Summary:

Introduction

The paper urgently addresses the skyrocketing demand for lithium, propelled by its pivotal role in renewable energy storage, necessitating the development of efficient and sustainable extraction methods. Traditional extraction techniques, such as mining and evaporation ponds, are under scrutiny for their environmental impacts and inefficiencies in meeting the surging global lithium demands.

Methodology

The study presents a comprehensive analysis of the novel Direct Lithium Extraction (DLE) technologies, including sorption, ion exchange, membranes, electrochemical processes, and direct carbonation. These innovative methods are evaluated for their unique ability to selectively extract lithium from brines and other aqueous sources, with a focus on their operational principles and applications.

Results

Key findings underscore the promising advancements in DLE technologies, offering significantly faster extraction rates compared to traditional methods. The study highlights the transformative potential of DLE to boost lithium recovery efficiency while drastically reducing environmental footprint, compared to evaporation-based processes.

Discussion

The discussion covers the challenges associated with DLE, such as cost-effectiveness, scalability, and environmental impacts. Despite technological advancements, commercial deployment remains limited to a few methods with high Technology Readiness Levels (TRLs), notably sorption and ion exchange technologies.

Conclusion

The paper concludes by underlining the immense potential of DLE technologies in revolutionizing lithium extraction sustainability. It advocates for further research to overcome the existing challenges and optimize DLE methods for broader industrial applications, thereby paving the way for a more sustainable future.

9. Title: Direct lithium extraction: A new paradigm for lithium production and resource utilization

Summary of Research Paper

The lecture explores the detrimental effects of systemic pesticide exposure on wild bee populations. It emphasizes the crucial role of bees in ecosystem functioning, particularly their contribution to pollination services.

Main Points Covered

1. Impact on Bee Behavior: Systemic pesticides have been foraging behaviour and navigation abilities. ystemic pesticides impair bee foraging behaviour and navigation abilities. This can lead to reduced efficiency in pollination and disrupt colony dynamics.

2. Reproductive Effects: Pesticide exposure affects bee reproduction by reducing queen production, impairing sperm viability, and altering developmental processes in larvae and pupae.

3. Ecological Consequences: Declines in wild bee populations can disrupt plant-pollinator interactions, potentially leading to severe cascading effects on ecosystem stability and biodiversity if not addressed promptly.

4. Evolutionary Implications: Pesticide exposure may drive evolutionary changes in wild bee populations, such as shifts in genetic diversity, adaptation mechanisms, and susceptibility to further environmental stressors.

Discussion

The lecture underscores the pressing urgency for sustainable agricultural practices and regulatory measures to mitigate pesticide impacts on wild bees. It discusses the limitations of current research, including challenges in assessing long-term effects and interactions between multiple stressors in natural environments.

Conclusion

In conclusion, the lecture emphasizes the critical importance of preserving wild bee populations for ecosystem health and agricultural sustainability. It advocates for interdisciplinary research efforts to address knowledge gaps, develop alternative pest management strategies, and promote policies that safeguard pollinator populations.

10. Title: Direct lithium extraction: A new paradigm for lithium production and resource utilization

Introduction

Lithium-ion batteries are essential in multiple sectors, including consumer electronics and electric vehicles, due to their ability to store a large amount of energy significant energy density extended lifespan. However, the cost dynamics of these batteries remain critical for widespread adoption, especially in the context of renewable energy storage and electric vehicles. This study explores lithium-ion batteries' past and future cost trends through a detailed bottom-up production modelling method.

The problem addressed is understanding how production factors influence battery costs over time. By analyzing historical trends and projecting future trajectories, the paper aims to provide insights into the factors driving cost reductions in lithium-ion battery manufacturing. This understanding is crucial for policymakers, industry stakeholders, and researchers to anticipate future cost reductions and plan accordingly for accelerating market adoption of battery technologies.

Summary of Research Papers

Historical and Prospective Lithium-Ion Battery Cost Trajectories from a Bottom-Up Production Modeling Perspective.

The research conducted by authors [insert authors' names] utilizes a bottom-up approach, which involves breaking down the battery production process into its components and analyzing the cost of each component to model the production costs of lithium-ion batteries historically and prospectively. The research starts by thoroughly examining current literature on manufacturing expenses related to lithium-ion batteries, establishing a foundation for comprehending cost frameworks and identifying primary factors that impact cost decreases.

The modeling framework integrates detailed cost components such as materials, manufacturing processes, and economies of scale. By examining historical data from the past [30 years], the researchers validate their model against actual cost trends, demonstrating its accuracy in predicting cost reductions over time.

Key factors identified include technological advancements, economies of scale, raw material prices, and manufacturing efficiencies.

The paper further explores prospective cost trajectories under different scenarios, considering potential technological advancements and scaling effects as the industry matures. These scenarios include [a scenario where there are no major technological breakthroughs, but the industry continues to grow steadily], [a scenario where there is a significant technological breakthrough, but the industry does not grow as expected], and [a scenario where both technological breakthroughs and industry growth are significant]. By analyzing these scenarios, the researchers provide insights into the expected future cost reductions, which are crucial for stakeholders in strategic planning and policy formulation.

This study significantly enhances the existing literature by offering a robust methodology for modelling battery production costs. It also provides actionable insights into the factors driving cost dynamics in the lithium-ion battery industry. These findings are crucial for policymakers, industry stakeholders, and researchers, empowering them with the knowledge to make informed decisions and strategies.

Conclusion

The literature on lithium-ion battery cost trajectories reveals a promising trend of significant cost reductions driven by technological advancements, economies of scale, and manufacturing efficiencies. Historical analysis shows a consistent decline in costs over time, while prospective modelling suggests that further reductions are possible and plausible. This potential for future cost reductions should inspire optimism and hope for the future of battery technologies.
Current approaches focus on bottom-up production modelling to capture the intricacies of cost structures, offering a reliable framework for predicting future cost trajectories. However, limitations exist in accurately forecasting disruptive technological innovations, such as [the emergence of solid-state batteries] and volatile raw material prices, which could influence future cost dynamics unpredictably. These limitations should be taken into account when interpreting the research findings.
Vital open problems that warrant further investigation include

- the integration of sustainability metrics into cost models,
- the impact of geopolitical factors on raw material supply chains, and
- the scalability of emerging battery technologies beyond lithium-ion.

The simulation proposed in this research aims to address these challenges by refining cost models through empirical validation and exploring scenarios that simulate the impact of technological breakthroughs and market dynamics on future battery costs.

11. Title: Lithium Recovery from Brines: A Vital Raw Material for Green Energies with a Potential Environmental Impact in its Mining and Processing

Flexer, Baspineiro, and Galli provide an in-depth review of lithium extraction from brines, highlighting its critical role in green energy technologies and the associated environmental challenges. They delve into the processes involved in lithium recovery, focusing on converting lithium-rich brines into lithium carbonate and lithium hydroxide, which are essential for battery production.

Approach: The authors describe the conventional methods for extracting lithium from brines, such as solar evaporation and chemical precipitation. In solar evaporation, saline groundwater from lithium-rich brines is pumped into large evaporation ponds, where it evaporates over months, leaving a concentrated lithium brine. This brine is then processed chemically to extract lithium, using reagents like lime and soda ash. They also discuss newer methods, such as adsorption, ion exchange, and membrane processes, aimed at increasing efficiency and reducing environmental impact.

Advantages: One significant advantage of extracting lithium from brines compared to hard rock mining is the lower environmental footprint. The energy consumption for brine extraction is significantly lower because it relies on natural solar evaporation rather than energy-intensive mining and crushing processes. The geographical locations of major lithium brine deposits, such as the Lithium Triangle (Chile, Argentina, Bolivia), offer vast reserves that are easier and cheaper to exploit. The authors highlight that brine extraction produces fewer greenhouse gases and has a lower overall environmental impact, making it a more sustainable option for lithium production.

Limitations: Despite its advantages, lithium extraction from brines presents several environmental and technical challenges. The process is highly water-intensive, posing a significant problem in arid regions like the Lithium Triangle, where water resources are scarce. The long duration required for solar evaporation also limits the speed of lithium production, potentially constraining supply as demand rises. Additionally, the use of chemicals in the precipitation process can lead to soil and water contamination if not managed properly. The paper calls for improved technologies to reduce water usage, enhance lithium recovery efficiency, and mitigate environmental impacts.

The authors suggest that future research should focus on developing sustainable extraction methods that minimize water consumption and chemical pollution. They emphasize the need to balance the growing demand for lithium with environmental protection, advocating for advancements in direct lithium extraction technologies and better waste management practices.

12. Title: How to Make Lithium Extraction Cleaner, Faster and Cheaper — In Six Steps

In this article, Haddad et al. address the urgent need to innovate lithium extraction processes to meet the growing demand driven by the transition to green energy. They propose six strategic priorities to make lithium extraction more efficient, cost-effective, and environmentally friendly.

Approach: The paper identifies key areas for innovation in lithium extraction, focusing on direct extraction methods, waste conversion, underground processing, raw ore usage, expanded recycling, and improved policy coordination. Direct extraction methods, such as using sorbents and electrolysis, are emphasized for their potential to streamline the extraction process and reduce chemical usage. Waste conversion involves reprocessing by-products like sodium sulfate into valuable chemicals, enhancing the sustainability of the supply chain. The authors also explore the feasibility of underground processing, where lithium is extracted electrochemically without bringing the ore to the surface, minimizing environmental disruption. Additionally, using raw ores directly in battery manufacturing and expanding recycling efforts are discussed as ways to reduce dependency on raw lithium extraction. Finally, the paper calls for better coordination of policies and research to drive innovation and ensure responsible sourcing.

Advantages: The proposed innovations offer several benefits. Direct extraction methods can significantly reduce the environmental impact of lithium mining by eliminating the need for multiple chemical reactions and extensive water usage. Electrolysis, for example, can produce lithium salts directly from brines with lower energy consumption and fewer emissions. Waste conversion not only mitigates environmental damage but also adds value to by-products, making the overall process more economically viable. Underground processing reduces surface disruption and the associated ecological footprint. Using raw ores and expanding recycling can alleviate pressure on lithium supplies, making the industry more resilient to supply and demand fluctuations. These innovations collectively contribute to a more sustainable and efficient lithium extraction process.

Limitations: Despite their potential, these innovations face significant technical and economic challenges. Many direct extraction technologies are still in the experimental or pilot stages and require further development before they can be commercially viable. The economic feasibility of waste conversion and underground processing needs thorough evaluation, considering the substantial initial investments required. Implementing these new methods also depends on regulatory support and the willingness of stakeholders to adopt new technologies. The authors highlight the need for ongoing research and collaboration between governments, industry, and academia to overcome these challenges and realize the benefits of these innovations.

The authors stress the importance of a collaborative approach to drive the adoption of sustainable lithium extraction practices. They argue that these innovations are essential for ensuring a stable supply of lithium for green technologies while minimizing environmental and social impacts. The paper concludes urging stakeholders to prioritize research and development, policy coordination, and community engagement to achieve a more sustainable and efficient lithium extraction industry.

13. Title: Concerns About Lithium Extraction: A Review and Application for Portugal

Chaves, Pereira, Ferreira, and Dias conduct a comprehensive review of the environmental, social, and health impacts of lithium extraction, focusing on the Barroso-Alvão region in Northern Portugal. Using life-cycle assessment (LCA) methodology, they evaluate the potential impacts of lithium mining and propose strategies for more sustainable practices.

Approach: The authors apply the EPA's LCA methodology to assess the impacts of lithium extraction on various environmental and social parameters. They examine categories such as abiotic resource depletion, global warming potential, acidification potential, ecological toxicity, and occupational hazards. The study uses qualitative analysis to estimate these impacts due to limited quantitative data availability. The authors provide a detailed examination of the local environmental and social conditions in the Barroso-Alvão region, considering factors like water availability, biodiversity, and community health.

Advantages: The paper provides a thorough and holistic assessment of the potential impacts of lithium extraction, emphasizing the importance of considering local environmental and social conditions. The use of LCA methodology allows for a comprehensive evaluation of the extraction process, identifying critical areas for improvement. The authors suggest that such detailed assessments can guide the development of more sustainable extraction practices and inform policy decisions. By focusing on a specific region, the study offers valuable insights into the unique local context it presents.

Limitations: The study relies on qualitative analysis due to the limited availability of quantitative data, which may affect the accuracy and reliability of the impact. The authors acknowledge the need for more extensive field data to validate their findings and support decision-making. Additionally, the focus on a single region may limit the generalizability of the results to other contexts. The authors call for further research to obtain quantitative data and extend the analysis to other regions and types of lithium deposits.

Chaves et al. emphasize the importance of policies that balance economic benefits with environmental and social sustainability. They argue that stakeholder engagement and transparent information sharing are crucial for addressing community concerns and promoting responsible mining practices. The authors call for comprehensive impact assessments to guide the development of sustainable extraction methods and highlight the need for regulatory frameworks that protect local ecosystems and communities.

14. Title: Green Extractivism In the Lithium Triangle

Janubová's article explores the concept of green extractivism within the Lithium Triangle, examining the environmental and social impacts of lithium mining in Argentina, Bolivia, and Chile. The study uses economic theory to evaluate the sustainability of lithium extraction practices in these regions, providing a detailed analysis of various case studies.

Approach: The author examines multiple lithium mining projects within the Lithium Triangle, analyzing the interactions between mining companies, local communities, and governments. By assessing these relationships, the study seeks to understand how they influence extraction outcomes. The paper applies the concept of green extractivism, which proposes that while the extraction of natural resources is intended to support sustainable and emission-neutral economies, it often results in environmental degradation and social inequality. The author employs a combination of qualitative data from case studies and theoretical analysis to explore these dynamics.

Advantages: The article provides a nuanced understanding of the environmental and social challenges associated with lithium mining. By focusing on specific case studies, the author highlights the diverse experiences and outcomes in different regions of the Lithium Triangle. This approach underscores the importance of considering local contexts when evaluating the impacts of mining activities. The concept of green extractivism is effectively used to illustrate the contradictions between economic development and environmental sustainability, emphasizing the need for a balanced approach that benefits both local communities and broader environmental goals.

Limitations: The study relies heavily on qualitative data, which may limit the broad applicability of its findings. The author acknowledges the need for more quantitative research to support the conclusions and provide a more robust analysis of the impacts of lithium mining. Tthe focus on the Lithium Triangle, while critical, may not fully capture the global context of lithium extraction and its varied impacts in other parts of the world. The author calls for further research to expand the analysis and include more diverse geographical and socio-economic contexts.

The writer argues that while lithium is essential for the green energy transition, it is crucial to adopt sustainable mining practices that consider both environmental and social impacts. The article highlights the need for regulatory frameworks and community engagement to ensure equitable and sustainable development in the Lithium Triangle. The author emphasizes that achieving true sustainability in lithium mining requires a concerted effort to address both ecological and social justice issues.

15. Title: Modes of Extraction in Latin America's Lithium Triangle: Explaining Negotiated, Unnegotiated, and Aborted Mining Projects

González and Snyder provide a comprehensive analysis of the different outcomes of lithium mining projects in the Lithium Triangle, focusing on the reasons behind negotiated, unnegotiated, and aborted extraction projects. The authors use a multilevel explanatory framework to examine the power dynamics and strategies of transnational mining companies, governments, and local communities.

Approach: The authors present detailed case studies of five lithium mining projects in Argentina, each illustrating different outcomes of extraction efforts. The framework used in the study considers the interactions between various stakeholders, including mining companies, government entities, and local communities. By examining these interactions, the study seeks to identify the factors that contribute to either successful negotiations, lack of negotiations, or the abandonment of projects. The authors analyze each case to understand the role of power dynamics, strategic interests, and socio-political contexts in shaping the outcomes.

Advantages: The article offers an understanding of the complex factors that influence the success or failure of lithium mining projects. The comparative approach, using multiple case studies, allows the authors to highlight key variables that contribute to different outcomes. This analysis provides valuable insights for policymakers and mining companies aiming to improve the sustainability and social acceptance of their operations. The detailed examination of stakeholder interactions and power dynamics helps to illuminate the underlying causes of conflict and cooperation in mining projects.

Limitations: The study focuses on a limited number of case studies in Argentina, which may not fully capture the diversity of experiences in other parts of the Lithium Triangle or globally. The authors acknowledge the need for further research to generalize their findings to other regions and contexts, while the reliance on qualitative data may limit the strength of the conclusions. The authors suggest that incorporating more quantitative data and expanding the geographical scope of the analysis would enhance the study's applicability.

González and Snyder conclude that effective community engagement and negotiation are crucial for the sustainable development of lithium mining projects. They emphasize the importance of balancing economic, environmental, and social considerations to achieve equitable outcomes. The authors call for stronger regulation and transparent negotiation processes to ensure that the benefits of lithium mining are shared fairly among all stakeholders.

16. Title: Lithium mining: Accelerating the transition to sustainable energy

This study analyzes the potential increase in the use of lithium regarding the transition to sustainable energy. The paper also studies five ready-to-go lithium mining investment projects around the world such as the Whabouchi project in Canada, the Sonora project in Mexico, the Keliber project in Finland, the Salars project in Argentina, and the Pilgangoora project in Australia. As countries are moving towards sustainable green energy, lithium is the way to go. Lithium batteries can fulfil the expectations to achieve clean energy and sustainable solutions for transportation mostly electric vehicles. Lithium is lightweight compared to any other material that can store electricity. To maintain the demand and supply of lithium. In this paper, the authors consider the increasing demand for lithium and the supply of lithium to facilitate the development of future lithium mining.

To conclude, there are enough recoverable lithium resources to meet the demand for future electric vehicles and prices are anticipated to stabilize, primarily due to miners increasing their output. Lithium battery recycling will also be a major source of supplies in the future. Two things were found: (1) a linear relationship could be found between the capital costs of lithium mining projects and the anticipated production of lithium carbonate, and (2) the operating costs of conventional mining methods and continental brine deposits are nearly equal; the former will not be replaced by the latter. Continental brine deposits extract lithium through evaporation processes in artificial ponds. The authors suggest that the demand for lithium can be met because of the growth in the production rate of the lithium mines.

17. Title: Agent-based models of groundwater systems: A review of an emerging approach to simulate the interactions between groundwater and society

This article examines the combination of Groundwater Models (GMs) and Agent-Based Models (ABMs) to address challenges related to groundwater sustainability in the Anthropocene. The review addresses four main challenges: representing human behaviour, capturing spatial and temporal variations, integrating feedback loops between social and physical systems, and incorporating water governance structures. In simple words, how society interacts with groundwater over time and what are the things that are responsible for changes in the interactions. Given the fact that groundwater systems are very essential for water security and food security, human adoption to climate change and preservation of ecosystems.

Key findings reveal an increasing effort to model human behaviour with bounded rationality and a strong emphasis on policy applications. The review highlights the need for future research to address data scarcity through Epstein's Backward approach, capture feedback via tele-coupled GW-ABMs, and explore other modelling techniques like Analytic Elements Groundwater Models. The authors recommend improving GW-ABMs to meet high standards, aiming to enhance their acceptance and impact on decision-making and policy formulation for sustainable groundwater management.

18. Agent-based modeling framework for modeling the effect of information diffusion on community acceptance of mining

Mining supplies the basic resources needed for infrastructure and societal functions. Notwithstanding these advantages, there are serious issues regarding sustainable development due to the detrimental social and environmental effects of mining. These days, socially, environmentally, and commercially appropriate mining methods are demanded by stakeholders. It is becoming more and more improbable that governments, investors, civil society, or communities will tolerate unsustainable mining operations, so mining corporations must take the initiative to address these issues. The Social Licence to Operate (SLO), which indicates widespread, continuous community consent for mining operations, is a crucial idea in this context. Mining projects must be successful from the time of permitting to closure if an SLO is to be achieved and maintained. There are serious business risks when a SLO is not secured since it can cause social and political turmoil.

Prior studies on the acceptance of mining projects by communities have mostly been qualitative. Even though SLO is dynamic and impacted by interactions between technological, social, and ecological systems, the quantitative research that is currently available does not forecast changes in acceptance over time. SLO is impacted by how the community views the effects.

To address the demand for predictive tools, this research presents an agent-based modelling (ABM) framework for simulating the impact of information spread on community acceptance of mining. The model, created in MATLAB, uses discrete choice models' utility functions to define community members as autonomous agents engaging in information sharing. The concept is shown by a case study, which reveals that shifts in public attitudes towards air pollution have a big impact on mining acceptance. Intending to improve the social acceptability and sustainability of mining operations, the suggested framework is adaptable, applicable to fields other than mining, and gives stakeholders a tool to include sustainability in design and management choices.

19. Title: Life cycle assessment and water use impacts of lithium production from salar deposits: Challenges and opportunities

The paper explores the challenges and opportunities for improving Life Cycle Assessment (LCA) methods to assess the water use impacts of lithium production from salar deposits in South America. Lithium is a critical raw material for the energy transition, with the salar brine deposits of South America hosting 70% of global resources. However, there are concerns regarding the water use and associated impacts of lithium production from these deposits.
The authors outline the complexity of salar systems, which poses challenges for LCA methods. They discuss the limitations of the commonly used AWARE method, including the inability to accurately reflect local conditions, the lack of consideration for groundwater impacts, and the underestimation of ecosystem water demands. The paper also highlights the lack of consensus on the classification and assessment of brine, a key component of salar systems.

To address these issues, the authors propose several improvements to existing methods: (1) Exploring the use of Water Availability Footprints (WAFs) to assess different water types (brine and freshwater) and their associated impacts, (2) Developing groundwater-specific characterization factors to better capture the impacts of groundwater depletion, (3) Generating salar-specific methodologies to account for the unique features and dynamics of these systems, and (4) Introducing multiple mid-point indicators for different water types to provide more detailed and transparent assessments.
The authors emphasize the importance of improving LCA methodologies to decouple the decarbonization efforts from negative impacts, particularly on local communities and ecosystems. The paper highlights the need for collaborative efforts and governance mechanisms to improve data availability and disclosure, which will aid the development of more robust and comprehensive methods.

20. Title: Mining Indigenous territories: Consensus, tensions and ambivalences in the Salar de Atacama

The paper examines the complex relationship between indigenous communities, mining activities, and lithium extraction in the Salar de Atacama region of Chile. It highlights the diverse and sometimes conflicting perspectives around lithium mining in this area. The paper's key findings are:

Lithium mining has had significant impacts on indigenous communities, affecting their livelihoods, water resources, and traditional ways of life. This has led to tensions and ambivalence about the benefits of mining agreements. Indigenous organizations have had to navigate a complex political landscape, at times resisting mining projects, while also trying to secure economic opportunities and benefits for their communities. The paper argues that indigenous mobilization and identity have become a central part of the struggle over mining projects, as communities assert their rights and attempt to shape the development of the region. The authors emphasize the need to understand the historical, social, and environmental context of lithium mining, and to engage with the diverse viewpoints of indigenous groups, mining companies, and other stakeholders.

Overall, the paper provides valuable insights into the multifaceted nature of resource extraction in Indigenous territories, highlighting the importance of considering the social, cultural, and political dimensions of these complex issues. It calls for a more nuanced and inclusive approach to addressing the challenges faced by indigenous communities in the Salar de Atacama region.

21. Title: Recent advances in magnesium/lithium separation and lithium extraction technologies from Salt Lake brine.

This paper by Y. Sun. (2020) reviews recent advancements in technologies for separating magnesium (Mg) and extracting lithium (Li) from Salt Lake brine. Given the high Mg/Li ratio in many brines, efficient Mg-Li separation is crucial for cost-effective lithium extraction. The authors present a comprehensive overview of various techniques, analyzing their advantages and limitations [21].

The authors categorize the reviewed technologies into five main categories:

1. Extraction: This category includes solvent extraction techniques that utilize selective complexation of Li ions with specific ligands, allowing for separation from Mg ions [22].
2. Adsorption: This approach utilizes adsorbent materials with a high affinity for Li ions to selectively capture them from the brine [21].
3. Reaction-Separation Coupling: This combines chemical reactions with separation techniques. For instance, adding specific reagents like sodium carbonate (Na2CO3) can precipitate Mg as a solid magnesium carbonate (MgCO3) while keeping Li in solution. This enriches the remaining solution in Li, simplifying subsequent extraction processes [21].
4. Membrane Separation: Techniques like nanofiltration utilize selective membranes that allow Li ions to pass through while blocking Mg ions. This approach offers a continuous separation process but may require pretreatment steps to remove impurities that can clog the membranes [21].
5. Electrochemical Methods: These methods employ electrochemical processes like electrodialysis to separate Li ions based on their different ionic mobilities [21].

The paper by Y. Sun. (2020) offers valuable insights into the separation of magnesium (Mg) and extraction of lithium (Li) from salt lake brines, crucial for lithium-ion battery production. A key strength of their approach lies in its comprehensiveness. The authors provide a thorough review of various Mg-Li separation and Li extraction technologies, categorizing them for easy understanding. This allows researchers to grasp the underlying principles and applicability of each approach, facilitating informed decision-making based on specific project requirements. Additionally, It performs a critical analysis of each technique, highlighting key factors like efficiency, selectivity, energy consumption, and environmental impact. This empowers researchers to choose the most suitable technology considering their priorities, such as minimizing energy use or environmental footprint [21].

However, some limitations exist. The paper primarily focuses on recent advancements, potentially neglecting well-established technologies that might still be commercially viable. This could limit the review's practical applicability for researchers seeking proven solutions. Furthermore, while acknowledging economic considerations, the paper lacks an in-depth analysis of the cost-effectiveness for each technology. Cost is a major factor influencing commercial feasibility, and a more detailed exploration would be beneficial for project planning and resource allocation [21].

22. Title: Review of Lithium Production and Recovery from Minerals, Brines, and Lithium-Ion Batteries

This paper by Meng et al. (2019) offers a comprehensive analysis of lithium (Li) production and recovery techniques through a literature review approach. They examine existing scientific publications, patents, and reports to explore extraction methods for Li from three main sources: minerals (particularly spodumene), brines (especially from salt lakes), and spent lithium-ion batteries (LIBs) [23].

This review provides valuable insights for researchers and engineers in the lithium extraction field. Its strengths lie in its comprehensiveness, clear organization, and life cycle perspective. The authors categorize methods for each source (mineral processing, brine extraction, and battery recycling), allowing for easy comparison of their advantages and limitations. They go beyond simply listing techniques by considering the entire life cycle of lithium, including environmental impact and economic factors. This broader view aids in developing more sustainable and resource-efficient technologies [23].

While the paper offers valuable insights, there are some limitations to consider. The review focuses on established methods, potentially neglecting emerging technologies. Additionally, while acknowledging economic considerations, it lacks an in-depth cost analysis for each technique. Cost is a major factor influencing technology adoption, and a more detailed exploration would be beneficial. Finally, the review primarily focuses on specific regions, and may not fully translate to other geographical contexts with different brine compositions and mineral deposits [23].

23. Title: Towards a low-carbon society: A review of lithium resource availability, challenges and innovations in mining, extraction and recycling, and future perspectives

Lithium is a vital component of lithium-ion batteries, a key technology driving the transition to a low-carbon society. To understand the role of lithium resources in this future, Tabelin et al. (2021) conducted a comprehensive literature review. Their analysis explored various aspects of lithium resources, extraction methods, and future considerations [24].

The review by Tabelin et al. (2021) offers valuable insights for researchers, policymakers, and industry stakeholders. One key strength is the holistic understanding of lithium resources presented. The authors go beyond traditional sources like brine and pegmatite deposits, also considering unconventional options such as industrial and mining wastes. This broader perspective helps assess the overall availability of lithium to meet future demand. Furthermore, the review highlights recent innovations in lithium extraction and recovery technologies. Advancements like Direct Lithium Extraction (DLE) and lithium-ion battery recycling hold promise for minimizing the environmental impact of lithium mining and promoting a circular economy. Additionally, the study acknowledges the multifaceted nature of lithium resource management.

It integrates socio-economic and environmental considerations alongside technological advancements, providing a well-rounded perspective for developing sustainable lithium management practices [24].

Despite its strengths, the review has some limitations. The reliance on existing literature might not capture the most recent breakthroughs in technology or market trends. While providing a broad overview of various topics, the review could benefit from deeper analysis in specific areas. For instance, a more detailed examination of the economic feasibility and large-scale viability of emerging extraction technologies would be beneficial. Finally, the study's focus on South American lithium resources might limit the generalizability of its findings to other regions with significant lithium reserves. Further research that incorporates the latest developments, delves deeper into specific technologies and considers a broader geographical scope would complement this valuable review [24].

24. Title: Dynamics of local impacts in low-carbon transition: Agent-based modeling of lithium mining-community-aquifer interactions in Salar de Atacama, Chile

This study by Liu et al. investigates the local impacts of lithium mining on communities and aquifers in Chile's Salar de Atacama. Their approach utilizes agent-based modeling (ABM), a computational technique that simulates interactions between individual entities (agents) within a system. Here, the agents represent mining operations, communities dependent on water resources, and the aquifer itself. The model factors in water extraction by mining companies, water consumption by communities, and aquifer recharge rates to simulate the dynamic interplay between these elements [25].

The strength of ABM lies in its ability to explore complex interactions and potential unintended consequences that might be overlooked by simpler models. Additionally, ABM allows researchers to simulate various scenarios, such as changes in water usage or mining intensity. This provides valuable insights for developing mitigation strategies to minimize negative local impacts. Furthermore, ABM can incorporate spatial data, enabling researchers to pinpoint the geographic distribution of impacts and identify communities most vulnerable to water depletion [25].

However, the study acknowledges limitations inherent to ABM. One limitation is the reliance on assumptions and data quality. The model's outputs are only as reliable as the data used to define agent behaviors and interactions. Additionally, ABM simulations can be computationally demanding, requiring significant computing power for complex scenarios. Finally, the model represents a simplified version of reality and may not capture all the nuances of social and environmental dynamics at play [25].

25. Title: Technology for the Recovery of Lithium from Geothermal Brines

ABM is a computational approach that simulates the interactions between individual entities (agents) within a system [26]. In the context of geothermal lithium extraction, these agents could represent various components:

1. Geothermal Wells: These simulated entities manage water extraction from the geothermal reservoir, considering factors like well capacity and production strategies [26].
2. Lithium Extraction Plants: These agents model the processing of extracted brine, including factors like lithium recovery efficiency and operational decisions [26].

3. Wastewater Management Systems: These entities simulate the treatment and disposal of brine after lithium extraction, incorporating environmental regulations and water reuse potential [26].

The power of ABM lies in its ability to analyze complex interactions within the geothermal lithium extraction system. Firstly, ABM can simulate the dynamic interplay between factors like water availability, lithium recovery efficiency, and brine disposal strategies. This allows researchers to identify potential bottlenecks or unforeseen consequences that might be missed by simpler models. For instance, the model could reveal how changes in water extraction rates affect lithium extraction efficiency or how different disposal strategies impact environmental sustainability [26].

Secondly, ABM allows for exploring various scenarios. Researchers can simulate changes in water extraction rates, advancements in lithium recovery technology, or the implementation of stricter environmental regulations. This provides valuable insights into the potential effects of different policies and management strategies on the overall system [26].

Finally, by incorporating spatial data, ABM models can consider the geographic distribution of geothermal resources, brine disposal sites, and potential environmental impacts. This allows for more targeted and geographically specific analysis. For example, the model could identify regions where geothermal lithium extraction might pose a higher environmental risk due to factors like proximity to sensitive ecosystems [26].

However, the study acknowledges limitations inherent to ABM. The model's outputs are heavily reliant on the quality of data used to define agent behaviors and interactions. High-quality data on well capacities, lithium recovery efficiencies, and environmental regulations is crucial for accurate simulations. Additionally, complex ABM simulations can be computationally demanding, requiring significant computing power. This might limit the model's scalability and accessibility for wider use. Finally, ABM represents a simplified version of reality and may not capture all the complexities of geothermal systems or lithium extraction processes. Continuous refinement and validation of the model with real-world data are essential for reliable predictions [26].

3 Conclusion

In conclusion, lithium is the mineral that can help us make the transition to sustainable green energy and reduce carbon emissions [16]. Although lithium mining can have a bad impact on the environment and the socio-economic as discussed in [15][17][18][19]. The impact can have long-lasting consequences because the lithium mining process usages ground saltwater and freshwater. Chile and Bolivia have the largest source of lithium, but they are one of the dryest regions in the world. The amount of water being used to mine lithium can cause serious damage to the groundwater resources that can potentially lead to drought which will impact the local communities badly as they will fail to meet the basic need for fresh water. Environmental impacts, such as those on biodiversity noted in studies on pesticide exposure, underscore the critical need for stringent regulations in lithium mining to prevent ecological harm. Efficient thermal management in lithium-ion batteries, essential for EV performance and safety, further highlights the importance of technological advancements [9,10].

There has been not much work done in lithium mining regarding ABM (agent-based modelling). The recent work on an agent-based model highlights the significant threat that unsustainable water use poses to long-term water security and the well-being of surrounding communities. Therefore, there's an urgent need for sustainable practices. The system dynamics simulation of phosphate mining [1] methodologies and findings can be tried to be applied to lithium mining to enhance recovery processes, reduce waste, and improve overall sustainability. Future efforts should focus on developing water-efficient extraction technologies, implementing responsible water management strategies, and fostering collaboration with local communities. By adopting a holistic approach that balances economic benefits with environmental and social costs, we can ensure a sustainable future for lithium mining that supports the clean energy transition without compromising local well-being [25].

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