

Environmental and Socio-Economic Impacts of Lithium Mining: A Comprehensive Review

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Abstract

The surge in demand for lithium, driven by the transition to renewable energy sources and the rise of electric vehicles (EVs), underscores its critical role in modern technology. However, the environmental ramifications of lithium mining present significant challenges. This comprehensive review examines the environmental impacts of lithium extraction on ecosystems, water resources, air quality, and local communities, offering a balanced view of its benefits and drawbacks. Despite its crucial role in green technologies, lithium mining has notable environmental costs, including water depletion, habitat destruction, soil erosion, air pollution, and chemical contamination. Water resources are heavily impacted, particularly by brine extraction, which consumes substantial quantities of water, exacerbating local water scarcity in arid regions like Chile's Atacama Desert. In addition, lithium extraction contributes to water pollution through the release of hazardous chemicals. Land degradation, resulting from habitat destruction and soil erosion, further threatens biodiversity and disrupts ecosystems. Air quality is compromised by the release of dust particles and toxic chemicals that poses health risks to mine workers and nearby communities. Moreover, chemical pollution from acid drainage and heavy metal release presents severe environmental and health risks. Socio-economic impacts, including community displacement and conflicts over water resources, are significant. Indigenous communities in the "Lithium Triangle" and other regions face disruptions to their traditional ways of life and livelihoods due to mining activities. Mitigation measures are essential to address environmental and socio-economic impacts of lithium mining. Key strategies include advanced water management, sustainable mining practices, strict regulation, community involvement, enhanced battery recycling, and investing in alternative energy storage materials. Balancing lithium's benefits for renewable energy and EVs with environmental protection requires understanding these impacts and adopting sustainable practices and technological innovations.

Keywords: Lithium Mining; Environmental Impacts; Water Scarcity; Heavy Metal Contamination; Environmental Health; Environmental Justice; Sustainable Mining

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INTRODUCTION

The transition to renewable energy sources and the proliferation of electric vehicles (EVs) have significantly increased the demand for lithium, a key component in rechargeable batteries (Zeng et al., 2019). Discovered by Swedish scientist Johan August Arfvedson in 1817 and first isolated by William Thomas Brande and Sir Humphry Davy in 1818, lithium has evolved from a minor metal with limited applications to a critical element in modern technology (Miśkowiec, 2023). The commercial production of lithium began in 1923 in Germany, and since then, its uses have expanded from ceramics and glass to being pivotal in the energy storage industry (Wietelmann & Klett, 2018).

Lithium is found in various geological formations, including underground deposits of brine, mineral ores, clay, seawater, and geothermal well brines (Murodjon et al., 2020). The largest reserves are located in Chile's Atacama Desert, Bolivia's Salar de Uyuni, Australia and Chinese mining regions (Cuahutencos, 2024). Recently, significant deposits have also been identified along the Nevada-Oregon border in the United States and in several African countries, including Zimbabwe, Nigeria, Namibia, and the Democratic Republic of Congo (Johnigan, 2024; Goodenough et al., 2021).

Despite the clear benefits of lithium for green technologies, its extraction and processing raise substantial environmental concerns. The environmental footprint of lithium mining includes water depletion, habitat destruction, soil erosion, air pollution, and chemical contamination. These impacts challenge the perception of lithium as a purely green resource (United Nations Environment Programme, 2023).

This study provided a comprehensive review of the environmental impacts of lithium mining, examining the effects on ecosystems, water resources, air quality, and local communities. It also explored mitigation measures and future directions for making lithium extraction more sustainable. Understanding these impacts is crucial for balancing the benefits of lithium in renewable energy and electric vehicles with the need to protect our environment.

METHODOLOGY

A comprehensive literature review was conducted to examine the environmental impacts of lithium mining. Utilizing academic databases such as PubMed, Scopus, and Google Scholar, searches were performed using keywords such as "lithium mining," "environmental impact," "water pollution," "air quality," "habitat destruction," and "socio-economic impacts." Articles, reports, and case studies published within the last two decades were meticulously selected for thorough analysis. Data collection encompassed diverse sources, including peer-reviewed journals, government reports, industry publications, NGO reports, and case studies.

Lithium Extraction Techniques

Lithium extraction is carried out primarily using two methods: hard rock mining, which entails extracting lithium from spodumene ore in hard rock deposits, utilizing conventional mining techniques to procure the ore for subsequent lithium isolation (Gao et al., 2023); and brine extraction, a process involving the pumping of lithium-rich brine from underground salt flats to the surface. Through a succession of evaporation processes, the brine is concentrated, yielding lithium-rich solids for further refinement. Brine extraction is prevalent in regions endowed with salt flats and subterranean reservoirs (Liu, et al., 2019).

ENVIRONMENTAL IMPACTS OF LITHIUM MINING

Impact on Water Resources

Water usage is a major environmental concern in lithium extraction, particularly with brine extraction methods, which consume substantial quantities of water. Studies have shown that currently, two-thirds of the world's lithium production is extracted from brines, a process that evaporates, on average, half a million liters of brine per ton of lithium carbonate produced (Flexer, 2018). This high water consumption can exacerbate local water scarcity issues, especially in arid regions like the Atacama Desert in Chile, where lithium extraction operations are prevalent (Moran et al., 2022). Consequently, with a significant portion of global lithium mining projects taking place in arid ecosystems, mining-induced water shortages can negatively affect the ability of surrounding communities to cultivate crops and raise livestock, leading to water-related conflicts like the Toconao conflict reported in northern Chile (FoEI, 2021).

In addition, lithium extraction can contribute to water pollution. A study on surface water quality at the Jiajika mine in China revealed that lithium extraction significantly influences the concentrations of arsenic, chromium, nickel, and vanadium in surface water (Gao et al., 2021). Similarly, an evaluation of the lithium pollution health risks at the largest lithium extraction industrial area in China revealed that lithium concentration in aquatic plants, such as water hyacinth, and in fishes, was significantly increased from upstream to downstream areas. This indicates a significant risk to local aquatic ecosystems, manifested in non-carcinogenic health effects experienced by local residents who consumed contaminated water and vegetables in the area (Yang et al., 2024).

Furthermore, chemicals used in processing lithium, such as hydrochloric acid, sulfuric acid, and other pollutants, have the potential to leach and contaminate water resources. This contamination impacts both surface water bodies and groundwater, posing risks to aquatic ecosystems and human health (Kavanagh et al., 2018).

Impact on Land Resources

Habitat destruction is a common consequence of hard rock mining, where extensive land disruption results in the loss of habitat for local flora and fauna. Such disturbances can have far-reaching ecological impacts, altering ecosystems and threatening biodiversity (Liu et al., 2019). Lithium is a non-renewable mineral and mining activities contribute to soil erosion, diminishing the land's agricultural potential and exacerbating environmental degradation. The erosion of topsoil not only compromises soil fertility but also disrupts ecosystem functions, further exacerbating the loss of habitat and biodiversity (Worlanyo & Jiangfeng, 2021).

Studies have shown that the world's biggest lithium mining site, located in the Salar de Atacama in Chile has witnessed extensive environmental degradation of human settlements, national reserves and salt flats over the past 20 years (Liu et al., 2019). The unregulated nature of lithium mining in many African countries has also given birth to a sector populated by unlicensed artisanal miners resulting in massive degradation of the environment. According to World Bank (2020) and Otorokpa et al. (2024), land degradation from mining and other activities has cost Zimbabwe, the biggest lithium producer on the African continent, an average of \$1.8 billion per year; this excludes the indirect costs such as poor crop yields due to diminished water supply and poor soils which has consequential effects on poverty and food insecurity.

In the Salar del Hombre Muerto region of Argentina, lithium mining has caused extensive soil contamination and changes in land use patterns, impacting local flora and fauna (Ortiz, 2021). This is similar to findings of a study on the impact of lithium mining operations in Clayton Valley, Nevada, USA, which reported that lithium mining can cause sinkholes and land subsidence, potentially damaging infrastructure and disrupting ecosystems (Saftner et al., 2023). Open-pit lithium mining in the Pilbara region of Australia has also caused significant environmental degradation, including habitat destruction and soil erosion, affecting local biodiversity and land stability (Dickson, 2022). In Western Australia, the Greenbushes lithium mine expansion has resulted in the degradation of surface topsoil, reduced soil function, and erosion, contributing to a loss of biodiversity in the region (Environmental Protection Authority, 2018).

Impact on Air Quality

The release of dust particles and toxic chemicals into the air during mining can result in respiratory problems, particularly due to exposure to particulate matter such as PM_{2.5}, which can travel into and deposit on the deeper parts of the lungs, and PM₁₀, which often deposits on the surfaces of the larger airways of the upper region of the lungs. This poses a major threat to the health of mine workers and surrounding communities due to the risk of pneumoconiosis and silicosis (Yu & Zahidi, 2023).

The evaluation of atmospheric air quality at the C57 lithium mine located in Gonçalo village of Guarda district in Portugal revealed the presence of air pollutants such as nitrogen dioxide and particulate matter (PM₁, PM_{2.5} and PM₁₀) (Rodrigues et al., 2019). Studies have shown that long-term exposure to nitrogen dioxide leads to emphysema-like structural changes in animals, thickening of the alveolar capillary membrane, loss of ciliated epithelium, and increases in lung collagen (Jarvis et al., 2010).

Furthermore, dust from lithium mines can negatively impact weather conditions, surface vegetation, and landscapes in addition, to the release of about 15 tonnes of CO₂ into the atmosphere for every tonne of lithium mined which exacerbates climate change (Luong et al., 2022; Otokpa et al., 2024). This undermines some of the environmental benefits associated with the use of lithium in renewable energy technologies, highlighting the complex trade-offs involved in lithium production.

Chemical Pollution

Acid drainage resulting from the use of sulfuric acid in lithium extraction processes is another serious threat to water and soil quality. Acid drainage can contaminate water bodies and soil, adversely affecting plant and animal life (Rezaie & Anderson, 2020). In addition, the lithium mining process releases heavy metals such as arsenic, mercury, and lead into the environment, posing significant risks to human health and ecosystems. A review of the impact of a large lithium mine in the fertile Radjevina region of western Serbia revealed that there is a real risk of causing an environmental catastrophe from the spillage of tailings with heavy metals into flooded rivers and arable land (Trpeski et al., 2021).

Studies have shown that global lithium concentrations in agricultural soils range from less than 10 to 300 mg/kg, with pollutant levels varying spatially and temporally; the increase in lithium mining and large-scale production of lithium batteries is expected to exacerbate bioaccumulation in plants and the food chain, potentially reaching harmful levels in humans and wildlife which can lead to dysfunctions in the thyroid, stomach, kidneys, and

reproductive systems at elevated intake levels exceeding 1.5 mM in serum (Shakoor et al., 2023).

Socio-Economic Impacts

Mining operations can have major socio-economic impacts on local communities. Community displacement is a significant issue, where the establishment and expansion of mining sites often force local populations to relocate, resulting in the loss of livelihoods and cultural disintegration. In the "Lithium Triangle" stretching across Argentina, Bolivia and Chile, local indigenous communities, such as the Atacameño people, have been displaced and faced disruptions to their traditional way of life due to lithium mining activities. The extraction of lithium has led to concerns over water shortages, which are critical for agriculture and livestock, further impacting their livelihood (Hegarty, 2023; Cuahutencos, 2024).

Comparably in the Salar de Uyuni, one of the world's largest salt flats located in the southwest of Bolivia, indigenous communities have also been affected by lithium mining projects. The extraction processes have caused environmental degradation and water scarcity, leading to conflicts and the displacement of local populations who rely on the land for their traditional practices and livelihoods (Sanchez-Lopez, 2019).

Studies have also shown that while the extraction and production of lithium has attracted significant investment, the socioeconomic outcomes in many places have been deeply disappointing and troubling. According to Takemura (2018), there is no development in the mining areas, but instead, widespread poverty and alarming negative environmental impacts.

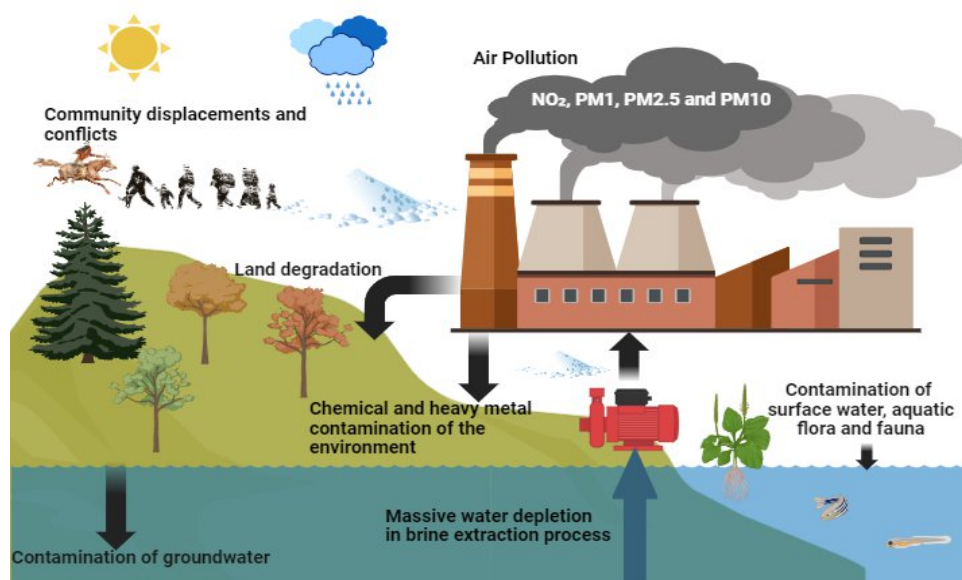


Figure 1: Environmental and socio-economic impacts of lithium mining

Mitigation Measures

A case study evaluating the Jadar lithium mining project in Serbia, covering the Adriatic Basin considered the only jadarite deposit in the world, presents a concerning picture for the environmental wellbeing of lithium mining regions, especially the mitigation of the environmental and socio-economic impacts of lithium mining shown in figure 1 above. The

study revealed that the project lacks a plan to monitor the environmental dimension of development or assess the environmental impact for each of the planned facilities in the area (Stefanović et al., 2023). Addressing the identified environmental and socio-economic impacts of lithium mining requires comprehensive mitigation strategies. Research has shown that implementing advanced water management techniques to recycle and reuse water in the mining process can significantly reduce water consumption and contamination (Miller, 2006), in the same vein adopting sustainable mining practices that minimize land disruption and use less harmful chemicals can help preserve local ecosystems and reduce pollution (Nathan et al., 2024). Furthermore, the strict regulation and monitoring of environmental impacts are essential to ensure compliance with environmental standards and best practices that can help mitigate the negative effects of mining (Agboola et al., 2020); moreover, involving local communities in decision-making processes and ensuring they benefit from mining activities through job creation and infrastructure development is vital for the socioeconomic development of mining regions (Esteves, 2008).

Alternatives and Future Directions

In order to reduce the global reliance on new lithium mining, enhancing the recycling of lithium from used batteries is a critical strategy. This not only conserves resources but also reduces environmental degradation associated with mining (Winslow et al., 2018). This is in addition to funding research and development of alternative materials for batteries such as sustainable composites, organic polymers and biodegradable alternatives that are less environmentally damaging but can provide sustainable solutions for energy storage (Mahmud, 2024). Furthermore, investing in technological innovations that make lithium extraction more efficient and environmentally friendly can mitigate the environmental and health impacts of lithium mining. The dynamic and ever-evolving nature of the lithium extraction industry necessitates continual adaptation to technological advancements and environmental considerations (Krishnan & Gopan, 2024). These approaches collectively aim to balance the growing demand for lithium with the need to protect the environment and support local communities.

CONCLUSION

Lithium is central to the global shift towards sustainable energy, especially in the context of electric vehicles (EVs) and renewable energy storage systems. However, its extraction imposes significant environmental and socio-economic challenges, necessitating a comprehensive and multifaceted approach to mitigate these impacts. The environmental footprint of lithium mining is profound, notably in water-scarce regions like the Atacama Desert, where extensive water usage exacerbates local scarcity. Habitat destruction and soil erosion further threaten biodiversity and disrupt ecosystems, while air pollution from mining operations poses severe health risks. Chemical pollution, including acid drainage and heavy metal release, contaminates water and soil, presenting long-term ecological and health hazards.

Socio-economic impacts, such as community displacement and conflicts over water resources, significantly affect local populations, especially indigenous communities in lithium-rich regions like the "Lithium Triangle." These impacts highlight the need for stringent regulations and sustainable mining practices that minimize ecological damage and ensure compliance with environmental standards. Technological advancements and

innovations in water management, such as recycling and reusing water, can significantly reduce the environmental footprint of lithium mining operations.

Engaging local communities in decision-making processes and ensuring they benefit from mining activities through job creation and infrastructure development is crucial for socio-economic sustainability. Furthermore, enhancing lithium recycling from used batteries and investing in the development of alternative materials for energy storage can reduce the reliance on new lithium mining and its associated environmental impacts. This evidence-based approach will ensure that the critical role of lithium in green technologies does not come at an unsustainable cost to our environment and society.

Authors' Contribution

- **Oche Otorkpa:** Conceptualization, Writing – original draft, Formal analysis, Writing – review & editing.
- **Abdullahi Aborode:** Conceptualization, Supervision, Validation, Writing – review & editing.
- **Bala Muhammad Tukur:** Formal analysis, Writing – review & editing.
- **Stephen Emmanuel:** Formal analysis, Writing – review & editing.
- **Faokunla Opeyemi:** Formal analysis.
- **Andy Anyalewachi Ukah:** Formal analysis, Writing – review & editing.

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Declaration of competing interest

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