The lithium investment in Portugal: Potential benefits and challenges

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Master's in Economics

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Resumo

A orientação para um futuro mais limpo e sustentável coloca o lítio, um componente essencial para o armazenamento de energia e a mobilidade elétrica, no centro das atenções a nível mundial. Portugal, que alberga reservas substanciais de lítio, encontra-se numa confluência em que o desenvolvimento económico e as práticas sustentáveis estão intrinsecamente ligados, necessitando de uma exploração rigorosa das vias e dos desafios gerados pelos empreendimentos de exploração do lítio.

Esta tese procura navegar através do complexo quadro de potenciais benefícios económicos, justaposto à miríade de desafios dispersos pelas esferas ambiental, social e regulamentar. A investigação é destilada em questões de investigação pungentes destinadas a dissecar os impactos económicos e a confrontar a viabilidade e a sustentabilidade dos projetos de lítio na nação, sustentadas por uma análise empiricamente informada através de um exame de dados secundários relevantes.

O estudo inclui aspetos críticos como a revisão da literatura, a exploração contextual do lítio em Portugal e discussões abrangentes sobre as conclusões e recomendações. Apesar de a investigação ter algumas limitações, principalmente relacionadas com a utilização de dados secundários e com os limites geográficos e metodológicos, pretende ser uma contribuição académica e prática significativa, iluminando caminhos para a definição de políticas, estratégias industriais e investigação futura.

Palavras-chave: Exploração de lítio, baterias de iões de lítio, indústria de lítio portuguesa

JEL: Q32, Q42

Abstract

The pivot towards a cleaner, more sustainable future places lithium, a quintessential component for energy storage and electric mobility, firmly in the global spotlight. Portugal, harboring substantial lithium reserves, stands at a confluence where economic development and sustainable practices are intricately entwined, necessitating a rigorous exploration of the avenues and challenges birthed by lithium exploration endeavors.

This thesis seeks to navigate through the complex tableau of potential economic benefits, juxtaposed against the myriad challenges dispersed across environmental, social, and regulatory spheres. The research is distilled into poignant research questions aimed at dissecting the economic impacts and confronting the feasibility and sustainability of lithium projects in the nation, underpinned by an empirically-informed analysis through an examination of relevant secondary data.

Woven into the fabric of the study are critical aspects including the literature review, contextual exploration of lithium in Portugal and comprehensive discussions on findings and recommendations. Although the research dances within certain limitations, primarily tethered to the utilization of secondary data and the geographical and methodological confines, it aspires to emerge as a significant academic and practical contribution, illuminating pathways for policy-making, industry strategies, and further research.

Keywords: Lithium exploration, lithium-ion batteries, Portugal's lithium industry

JEL: Q32, Q42

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CHAPTER 1

Introduction

In the contemporary epoch, lithium has ascended to prominence, solidifying its stature as a cornerstone in technological advancements, energy storage, and the electric vehicle (EV) sector, owing to its unparalleled electrochemical potential. With the burgeoning demand for clean energy and electric mobility, lithium, as a principal component of rechargeable batteries, has become imperative in sculpting a sustainable future, subsequently kindling global interest in its exploration and production.

In the context of Portugal, this indispensable mineral is not merely a component; it potentially represents a nexus between bolstering economic development and weaving a trajectory toward a sustainable future. The nation is endowed with significant lithium reserves, forging an opportunity for it to play a pivotal role in the global lithium market.

However, lithium exploration and its subsequent production encompass a spectrum of implications and intricate challenges that warrant meticulous exploration. The delineation between harnessing the economic potentials, such as elevating Gross Domestic Product (GDP), bolstering exports, and generating employment, and ensuring sustainable, environmentally congenial practices is nebulous and complex.

This research endeavors to weave through this complexity, offering a nuanced examination of lithium exploration in Portugal. The aim is to dissect the multifaceted economic impacts, scrutinizing aspects like GDP, exports, and job creation, while concurrently delving into the challenges poised in the environmental, social, and regulatory realms.

The rationale underpinning this study emanates from a discernible lacuna in comprehensive research that cohesively intertwines the economic benefits and multifarious challenges of lithium exploration in Portugal. Moreover, as the world pivots toward greener energy and sustainability, understanding the implications of lithium exploration becomes paramount, not just for Portugal but as a template for other nations nurturing similar ambitions. Thus, this thesis aspires to contribute a granular, empirically grounded analysis, propelling forward the discourse on lithium exploration, its economic potentials, and the inherent challenges enveloping it.

In synthesizing these aspects, this research does not only seek to add to the academic repository but also to influence policy-making and strategic decisions in the realm of mineral exploration and sustainable development, thereby intertwining economic progression with conscientious, sustainable practices.

1.1 Problem Statement and Research Questions

Navigating through the manifold of opportunities offered by lithium exploration, Portugal is confronted with a kaleidoscope of complexities and challenges that potentially permeate various sectors of the nation. The juxtaposition of anticipated economic boons against a backdrop of potential environmental, social, and regulatory tribulations presents a multifaceted problem that demands an in-depth, scholarly inquiry.

The economic canvas of lithium exploration, while ostensibly affluent with prospects such as enhancing GDP, spurring exports, and fomenting job creation, also beckons queries regarding the longevity and sustainability of such impacts on both national and regional economic development. Concomitantly, the challenges that drape across environmental conservation, social acceptance, and adherence to regulatory frameworks, intertwined with promises of socio-ecological betterment, require a meticulous analysis to decipher the real and perceived impact of lithium projects within Portugal.

This labyrinthine scenario conjures critical research inquiries, which this thesis seeks to unravel:

"How do the multifaceted economic impacts of lithium exploration in Portugal, encompassing aspects like GDP, exports, and job creation, influence national and regional economic development, and what can be projected regarding its sustainable impact on the economy?"

The above query seeks to dissect the economic pillars influenced by lithium exploration, aiming to map the tangible and intangible impacts while projecting future trajectories in light of sustainability.

"How do the challenges faced in environmental, social, and regulatory domains impact the feasibility and sustainability of lithium projects in Portugal, especially concerning regulatory adherence and promises of social and ecological betterment?"

This question aims to delve into the intricate challenges that span across various domains, examining their implications on the feasibility and sustainability of lithium projects, while critically evaluating the adherence to regulatory structures and promises made in socio-ecological contexts.

In seeking answers to these questions, this research endeavors to navigate through the economic, environmental, and social tapestry of lithium exploration in Portugal, aiming to furnish a balanced, empirically-informed analysis that could steer academic discourse and pragmatic decision-making in a direction that amalgamates economic aspirations with a tenet of sustainability and ethical practices.

1.2 Research Objectives and Significance

The strategic intent of this thesis orbits around a meticulous exploration of lithium endeavors in Portugal, seeking to establish an articulate connection between the economic, environmental, and social vectors that are influenced by and influence lithium exploration and production. Thus, the study is guided by the ensuing objectives:

1. Analyze the economic repercussions of lithium exploration on Portugal's national and regional development, focusing on metrics such as GDP, exports, and employment opportunities.
2. Examine the sustainable impact of lithium mining activities on the economy, exploring the durability and robustness of economic gains.
3. Access the challenges posed by environmental, social, and regulatory contexts, with a particular lens on the adherence to and implementation of regulatory frameworks and pledges of socio-ecological improvements.

In the crucible of lithium exploration, a nuanced, academically robust exploration of both the economic boons and potential challenges is quintessential. The significance of this thesis cascades into several pivotal realms, offering myriad contributions:

- **Academic Contribution:** The thesis strives to enrich the academic discourse, serving as a beacon that enlightens the path of future researchers exploring mineral exploration and its multifaceted impacts.
- **Policy Implication:** The findings are poised to serve as a robust framework to policymakers, potentially illuminating facets that demand attention, enabling them to sculpt policies that deftly balance economic advancement with steadfast sustainability and social equity.

- **Industrial Insight**: For the industry stakeholders, this research intends to delineate the economic and regulatory landscape, aiding in crafting strategies that are not only economically viable but also socially and environmentally responsible.
- **Sustainable Development:** Through a dive into the sustainability aspect of lithium exploration, this research aims to shed light on the pathways that align with the broader objectives of sustainable development, offering a template that can be mirrored in other similar contexts globally.

In culmination, the research propels not merely as an academic exercise but as a keystone that potentially influences tangible, real-world decisions and strategies, embedding its significance in the realms of academia, policy-making, industry planning, and sustainable development, each of which are instrumental in shaping the future trajectory of lithium exploration in Portugal and beyond.

1.3 Thesis Structure

The architectural scaffold of this thesis is structured to provide a seamless, logical progression through the different aspects of the study:

- **Literature Review:** Discourse on lithium's global importance, providing a theoretical bedrock upon which the research is anchored.
- **Contextualization:** Analyze the current status and significance of lithium exploration in Portugal, addressing its particular challenges and implications.
- **Methodology:** An exposition of the research design, data collection, and analytical strategies employed to ensure the robustness and validity of the findings.
- **Results, Findings, and Discussion:** A presentation and discussion of the research findings, mapped against the research questions and objectives.
- **Conclusion and Recommendations:** Final reflections, implications of the findings, and strategic recommendations, tethered to the data and analyses from preceding chapters.

In its entirety, the thesis aspires to weave through these chapters, to coalesce into a tapestry that provides a balanced exploration of lithium's potential benefits and challenges within the Portuguese landscape.

CHAPTER 2

Literature Review

Lithium, a member of the alkali metal group on the periodic table, holds the distinction of being the lightest among solid metals. Discovered in the year 1817 by the Swedish chemist *Johan August Arfwedson*, this element is not only historically significant but also possesses a wide array of applications in modern technology. Constituting approximately 0.002 percent of Earth's crust, lithium can primarily be found in mineral petalite, brine deposits, and as salts in mineral springs. It is also available in pegmatite ores such as spodumene (LiAlSi2O6), lepidolite (of varying structure), and amblygonite (LiAlFPO4) ores, with Li2O contents ranging between 4 and 8.5 percent[1].

The total known reserves of lithium globally are estimated at 26,000,000 tons. Chile is at the forefront with reserves amounting to 9,300,000 tons, followed by Australia with 6,200,000 tons. Argentina and China also hold considerable reserves, calculated at 2,700,000 and 2,000,000 tons respectively. Portugal, which is the focus of this thesis, ranks as the ninth largest lithium reserve as of 2023, with an estimated 60,000 tons[2]. Although this figure is relatively modest when compared to leading countries, it poses a potentially valuable exploration opportunity for Portugal.

When it comes to production statistics for the year 2023, the data - excluding the United States - reveals a total mine production of 130,000 tons. Australia leads this metric, accounting for 61,000 tons, whereas Chile, despite having the largest reserves, is the second-largest producer with 39,000 tons. China and Argentina follow with 19,000 and 6,200 tons respectively. In the case of Portugal, the production is currently at 600 tons, indicating substantial room for growth[3].

Over the years, the end-use market for lithium has experienced notable shifts, with batteries gaining increasing importance. Specifically, from 2021 to 2023, the share of lithium used in batteries rose from 71 percent to 80 percent. To further illustrate this point, let's compare the top three uses of lithium for the years 2021, 2022, and 2023:

[1] Dye. (2023, October 9). *lithium*. https://www.britannica.com/science/lithium-chemical-element

[2] USGS. (2023). LITHIUM. In *https://pubs.usgs.gov/periodicals/mcs2023/mcs2023-lithium.pdf*.

[3] Ibid

In 2021: Batteries accounted for 71 percent, ceramics and glass for 14 percent, and lubricating greases for 4 percent[4].

In 2022: Batteries increased their share to 80 percent, ceramics and glass decreased to 7 percent, and lubricating greases remained at 4 percent[5].

In 2023: Batteries further solidified their dominance with 80 percent, followed by ceramics and glass at 7 percent, and lubricating greases at 4 percent[6].

This trend clearly demonstrates a growing focus on lithium-ion battery technology, predominantly driven by the burgeoning electric vehicle industry.

In summary, lithium remains an indispensable element in modern technology and industry, with an increasingly important role in battery manufacturing. Its reserves, current production rates, and shifting consumption patterns all point toward a promising trajectory. For Portugal, the key question is the commercial viability of exploring its ninth-largest global reserve of 60,000 tons[7], a topic that certainly warrants further scholarly investigation.

2.1 Key players

The global lithium industry is dominated by a select group of companies, each having its own unique market position, capabilities, and geographic presence. In the global landscape, the top five largest lithium companies by market capitalization are[8]:

Jiangxi Ganfeng Lithium Co. Ltd: Headquartered in China, this company boasts a market capitalization of $38.6 billion. It is primarily engaged in the research, development, production, and sales of lithium products. Jiangxi Ganfeng Lithium Co. Ltd reported a revenue

[4] USGS. (2021). LITHIUM. In *https://pubs.usgs.gov/periodicals/mcs2021/mcs2021-lithium.pdf*.

[5] USGS. (2022). LITHIUM. In *https://pubs.usgs.gov/periodicals/mcs2022/mcs2022-lithium.pdf*.

[6] USGS. (2023). LITHIUM. In *https://pubs.usgs.gov/periodicals/mcs2023/mcs2023-lithium.pdf*.

[7] Ibid

[8] Skidmore. (2021, August 26). *Top 5 largest lithium mining companies in the world*. https://www.mining-technology.com/features/top-5-largest-lithium-companies/

of $839.26 million in 2020, which is nearly double the $432.11 million it reported in 2016. Importantly, the company holds lithium resources across Australia, Argentina, and Mexico.

Albemarle: Based in Charlotte, North Carolina, Albemarle commands a market cap of $26.8 billion. The company operates through three main divisions: lithium, bromine specialties, and catalysts. Notably, as of 2020, Albemarle was the largest provider of lithium for electric vehicle batteries.

Tianqi Lithium: Another Chinese firm, Tianqi Lithium holds a market cap of $24.39 billion. It is the world's largest hard-rock lithium producer and has resource and production assets across Australia, Chile, and China. In 2018, Tianqi Lithium controlled more than 46% of the global production of lithium.

Sociedad Química y Minera de Chile (SQM): This Chilean chemical company has a market cap of $14.03 billion. The company's primary production facilities are in the Atacama Desert, situated between Chile's I and II regions. In terms of production, SQM generated 72.2 thousand tonnes of lithium carbonate at their Salar de Atacama mine in 2020. This figure is almost double the 38 thousand tonnes it produced in 2011.

Pilbara Minerals: An Australian lithium mining company, Pilbara Minerals has a market cap of $6.8 billion. The company is focused on the development of lithium and tantalum projects and owns 100% of the world's largest independent hard-rock lithium operation, situated in Western Australia's resource-rich Pilbara region.

In summary, the lithium industry is characterized by a high degree of concentration, with a select few companies commanding significant market capitalizations and diverse asset holdings. These leading firms are well-capitalized and exert considerable influence over global lithium reserves and production. Their impact is manifold, from fueling the burgeoning electric vehicle battery market to consistently ramping up production capacities. These major companies play a significant role in influencing the direction of the global lithium industry.

2.2 Lithium-ion batteries market

The lithium-ion battery market has seen remarkable growth and transformation since its inception. First commercialized by Japan's Sony in 1991, lithium-ion batteries quickly gained traction due to their high energy density, safety, recharge time, and cost-efficiency compared to other alternatives like nickel-metal batteries. Initially, these batteries found their main application in consumer electronics. However, with technological advancements, their range of applications has significantly expanded. They are now commonly used in devices such as mobile phones, laptops, digital cameras, and power tools[9].

The global lithium-ion battery market was valued at about 40.5 billion U.S. dollars in 2020. Despite the prevalence of consumer electronics in the market, the small energy capacities of gadgets like phones mean that their demand, in terms of gigawatts, is relatively low. However, this is set to change drastically. The market is expected to grow with a projected Compound Annual Growth Rate (CAGR) of 14.6%, reaching almost 92 billion U.S. dollars by 2026[10].

One of the main factors driving this explosive growth is the electrification of transport. Several countries are moving towards more environmentally sustainable methods of living, with the adoption of electric vehicles (EVs) being the most notable change. This transition is resulting in a likely decrease in the use of gasoline in cars. Countries like China have already seen significant growth in EV sales; over 430,000 units were sold in the first half of 2019 alone[11]. By 2021, more than 3.5 million EVs were sold in China[12]. Due to these trends, by 2050, it is expected that more than 80% of new cars sold will be battery powered[13].

[9] Statista Research Department. (2023, October 9). Lithium-ion batteries - statistics & facts. Retrieved from https://www.statista.com/topics/2049/lithium-ion-battery-industry/#topicOverview

[10] Statista Research Department. (2023, October 9). Projected size of the global lithium-ion battery market from 2020 to 2026. Retrieved from https://www.statista.com/statistics/1011187/projected-global-lithium-ion-battery-market-size/

[11] Statista Research Department. (2023, October 9). Projected battery demand worldwide by application 2020-2030. Retrieved from https://www.statista.com/statistics/1103218/global-battery-demand-forecast/

[12] Statista Research Department. (2023, March 23). Electric car stock in China 2009-2021. Retrieved from https://www.statista.com/statistics/1050044/china-electric-car-stock/

[13] Carlier, M. (2022, September 30). Projected electric vehicle market share of global sales 2030-2050. Retrieved from https://www.statista.com/statistics/1202364/ev-global-market-share/

The global demand for lithium-ion batteries is, therefore, expected to increase from 185 GWh in 2020 to a staggering 2000 GWh by 2030[14]. Specifically, the demand is projected to reach approximately 1,525 gigawatt-hours in 2030[15]. Out of this, Chinese demand for lithium-ion batteries is expected to be around 740 GWh, accounting for almost half of the global demand in that year[16].

The scale of this demand has triggered an increase in production capacities. Between 2015 and 2020, the number of lithium-ion battery factories under construction or planning rose from just four to 181[17]. This surge was further accelerated by the Covid-19 pandemic; the global build-out of lithium-ion factories increased by more than 50% in 2020 compared to the previous year[18]. Worldwide, lithium-ion battery production capacity is projected to grow from almost 300 gigawatt-hours in 2018 to over two terawatt-hours by 2028[19].

However, the distribution of this manufacturing capacity is notably uneven. In 2020, China produced around 77% of batteries that entered the global market[20], and out of the 181 factories under construction and planning, 136 were in China[21]. European countries, although planning extensive investments in lithium-ion battery manufacturing, are still catching up. By

[14] Statista Research Department. (2023, October 9). Projected battery demand worldwide by application 2020-2030. Retrieved from https://www.statista.com/statistics/1103218/global-battery-demand-forecast/

[15] Statista Research Department. (2023, January 6). Projected demand for lithium-ion batteries worldwide in EVs 2019-2030. Retrieved from https://www.statista.com/statistics/309570/lithium-ion-battery-market-in-electric-vehicles/

[16] Placek, M. (2023, September 27). Lithium-ion battery demand in EVs worldwide by region 2019-2030. Retrieved from https://www.statista.com/statistics/1103229/global-battery-demand-by-region-forecast/

[17] Statista Research Department. (2023, October 9). Lithium-ion batteries - statistics & facts. Retrieved from https://www.statista.com/topics/2049/lithium-ion-battery-industry/#topicOverview

[18] Placek, M. (2023, January 6). Undergoing and planned build-out of lithium-ion battery factories worldwide 2015-2020. Retrieved from https://www.statista.com/statistics/1247301/build-out-of-lithium-ion-battery-factories/

[19] Statista Research Department. (2023, October 9). Lithium-ion batteries - statistics & facts. Retrieved from https://www.statista.com/topics/2049/lithium-ion-battery-industry/#topicOverview

[20] Ibid

[21] Placek, M. (2023, January 6). Undergoing and planned build-out of lithium-ion battery factories worldwide 2015-2020. Retrieved from https://www.statista.com/statistics/1247301/build-out-of-lithium-ion-battery-factories/

2025, it is expected that China will manufacture about 65% of the world's lithium-ion batteries, with European production accounting for around 25%[22]. Germany is poised to become the second-biggest producer, making up about 11% of the global production capacity by 2025[23].

In the United States, the Tesla Gigafactory stood as the largest lithium-ion battery factory in 2020 with a production capacity of 37 gigawatt-hours, while LG Chem in Poland and CATL in China also stood as global leaders that year with matching production capacities of 24 gigawatt-hours[24].

As the market grows, the demand for key battery minerals like graphite and lithium is also expected to skyrocket by 2028. Graphite, which is used in battery anodes, is forecasted to have a demand exceeding two million metric tons in 2028. Lithium, another crucial battery component, is projected to have a demand of about 1.9 million metric tons in the same year[25].

The decline in the prices of lithium-ion battery packs to 132 U.S. dollars per kilowatt-hour in 2021, a nearly 90% decrease since 2010[26], indicates significant technological advancements and production efficiencies. However, the slight uptick to 141 U.S. dollars per kilowatt-hour in 2022[27] could signal that demand is outstripping supply, particularly given that lithium is a finite resource.

This dynamic is bringing greater attention to the recycling of lithium-ion batteries. With the lithium-ion battery recycling market valued at about 1.3 billion U.S. dollars in 2019 and

[22] Statista Research Department. (2023, October 9). Lithium-ion batteries - statistics & facts. Retrieved from https://www.statista.com/topics/2049/lithium-ion-battery-industry/#topicOverview

[23] Statista Research Department. (2023, October 20). Share of the lithium-ion battery production capacity worldwide by country 2021&2025. Retrieved from https://www.statista.com/statistics/1249871/share-of-the-global-lithium-ion-battery-manufacturing-capacity-by-country/

[24] Placek, M. (2022, September 28). Largest lithium-ion battery factories worldwide by production capacity 2020. Retrieved from https://www.statista.com/statistics/1246713/largest-lithium-ion-battery-factories-worldwide/

[25] Statista Research Department. (2023, October 23). Projected battery demand worldwide by application 2020-2030. Retrieved from https://www.statista.com/statistics/1103218/global-battery-demand-forecast/

[26] Statista Research Department. (2023, October 9). Annual prices of lithium-ion battery packs 2010-2020. Retrieved from https://www.statista.com/statistics/1042486/india-lithium-ion-battery-packs-average-price/

[27] Statista Research Department. (2023, October 19). Lithium-ion battery price worldwide 2013-2023. Retrieved from https://www.statista.com/statistics/883118/global-lithium-ion-battery-pack-costs/

expected to grow to around 11 billion U.S. dollars by 2027, at a CAGR of 32%[28], recycling is becoming increasingly crucial as a strategy to manage supply constraints, especially as the world transitions to a renewable energy-based economy where electric vehicles play a significant role.

2.3 The need for recycling

As global efforts to combat climate change intensify, the focus is turning to various sectors that contribute to carbon emissions, including transportation. One solution that has gained traction is the electric vehicle market, which heavily relies on lithium-ion batteries. However, the rise in electric vehicles also puts a spotlight on the environmental implications of lithium-ion battery production and disposal.

Firstly, improper disposal of lithium-ion batteries poses a severe environmental risk. These batteries contain hazardous materials that can leach into the soil and water, causing contamination and harm to ecosystems. The threat becomes increasingly significant given the projected market demand for lithium-ion batteries, which is expected to reach over 1,500 gigawatt-hours by 2030[29]. With more batteries reaching the end of their lifespan, the necessity for effective and safe recycling methods becomes even more pressing.

Secondly, the focus on recycling is also motivated by the scarcity of lithium as a natural resource. The skyrocketing demand for lithium-ion batteries, driven by the booming electric vehicle market, is difficult to sustain solely through new lithium sources. As of 2022, batteries consumed 80 percent of the world's lithium supply, with this trend showing no signs of slowing down[30]. Finding a more sustainable way to meet this demand is imperative.

Thankfully, recycling initiatives are beginning to gain momentum. The global market for lithium-ion battery recycling is projected to grow substantially, from approximately 1.3

[28] Alves, M. (2023, October 9). Projected size of the global market for lithium-ion battery recycling 2019-2027. Retrieved from https://www.statista.com/statistics/1103263/li-ion-battery-recycling-market-size/

[29] Statista Research Department. (2023, January 6). Projected demand for lithium-ion batteries worldwide in EVs 2019-2030. Retrieved from https://www.statista.com/statistics/309570/lithium-ion-battery-market-in-electric-vehicles/

[30] Garside. (2023, August 29). Lithium end-use share in the global market 2022. Retrieved from https://www.statista.com/statistics/268787/lithium-usage-in-the-world-market/

billion U.S. dollars in 2019 to an expected 11 billion U.S. dollars by 2027[31]. These efforts are not just a response to environmental hazards, but also a proactive measure to alleviate the strain on the finite lithium supplies.

In conclusion, while the growing adoption of electric vehicles represents a positive step toward a more sustainable future, it comes with its own set of challenges, most notably the environmental impact of lithium-ion battery disposal and the increasing pressure on limited lithium resources. Therefore, the rise of recycling initiatives is not just promising but paramount, serving a dual purpose: mitigating environmental risks and helping meet the skyrocketing demand for lithium in a more sustainable manner.

2.4 Alternatives to lithium-ion batteries

As the world moves toward a more sustainable future, the quest for efficient, affordable, and eco-friendly energy storage has never been more critical. Lithium-ion batteries have long been the standard in this arena, but with rising concerns about the supply of key materials like lithium and cobalt, the time is ripe for alternatives. Here we delve into three promising contenders: solid-state batteries, sodium-ion batteries, and iron-based batteries[32].

Solid-State Batteries

In the world of electric vehicles (EVs), solid-state batteries are gaining prominence. Companies like Quantumscape, which went public in 2020 and has a commercialization deal with Volkswagen targeted for 2025, are leading the charge. Solid-state batteries replace the liquid electrolyte found in lithium-ion batteries with ceramics or other solid materials. This seemingly simple swap holds transformative potential: it could significantly improve the energy density, thereby allowing for greater driving range in EVs. Additionally, solid-state batteries could enable faster charging times and offer an extra layer of safety by reducing the fire risk associated with liquid electrolytes. However, there are challenges to overcome, such as degradation over time and manufacturing complexities, which make it unlikely that these batteries will appear in vehicles on the road by the end 2023.

[31] Alves, B. (2023, October 9). Projected size of the global market for lithium-ion battery recycling 2019-2027. Retrieved from https://www.statista.com/statistics/1103263/li-ion-battery-recycling-market-size/

[32] Crownhart. (2023, January 4). What's next for batteries. https://www.technologyreview.com/2023/01/04/1066141/whats-next-for-batteries/

Sodium-Ion Batteries

Another alternative that veers away from lithium-ion chemistry is sodium-ion batteries. Chinese battery giant CATL is reportedly gearing up to mass-produce these batteries in 2023. These batteries may not necessarily outperform lithium-ion batteries in terms of energy density or charging times, but they have a distinct advantage in cost. Sodium is more abundant and less expensive than lithium, making sodium-ion batteries potentially more economical. However, questions about their suitability for high-demand applications like EVs remain. That's why some companies are considering these batteries for less demanding applications, such as stationary storage or micromobility devices like e-bikes and scooters.

Iron-Based Batteries

While lithium-ion batteries are not ideal for stationary storage, iron-based batteries are emerging as strong contenders in this sector. Companies like Form Energy, which recently announced a $760 million manufacturing facility in Weirton, West Virginia, and ESS in Oregon, are pioneering technologies that could revolutionize grid storage. Specifically, Form Energy is developing an iron-air battery that uses a water-based electrolyte and stores energy through reversible rusting. This innovation is particularly significant as the need for electricity storage grows in tandem with the increasing installation of variable renewable power sources like wind and solar.

The landscape of battery technology is shifting under the weight of global demands for cleaner, more sustainable energy options. Although lithium-ion batteries remain prevalent in the market, they are increasingly being challenged by alternative technologies. Each alternative—solid-state for potentially longer-range and quicker-charging EVs, sodium-ion for cost-effectiveness, and iron-based for efficient grid storage—brings unique benefits and challenges to the table. As these alternative technologies edge closer to commercial viability, their influence could be transformative, challenging the current stronghold that lithium-ion batteries have in society. Therefore, it is paramount to closely monitor these emerging options when analyzing the future of lithium-ion batteries.

Lithium stands as a key element in the global shift toward renewable energy, primarily through its critical role in lithium-ion batteries. The lithium-ion battery market shows a strong potential for growth, although this trajectory is subject to various sustainability considerations.

Concerns about limited resources and the environmental impact of lithium extraction and processing have sparked debates about the long-term sustainability of relying so heavily on this element.

Recycling of lithium presents one avenue to address some of these challenges, but it may not be sufficient to entirely mitigate the concerns related to sustainability. In light of this, attention is increasingly turning toward alternative battery technologies. Options such as solid-state batteries, sodium-ion batteries, and iron-based batteries offer different benefits and drawbacks, but all serve to illustrate that the energy storage landscape remains in flux. These emerging technologies have the potential to significantly alter supply and demand dynamics for lithium.

While the focus of this thesis is the lithium industry, it is important to consider that ongoing research into alternative technologies could present more sustainable or efficient options. These alternatives, if commercialized at scale, could meaningfully impact the lithium market and its projected path of growth.

The next chapter will delve into a more localized examination by exploring the state of the lithium industry in Portugal. This will serve to contextualize the broader themes discussed here, offering a nuanced view of lithium's role in energy transition efforts on both a global and local scale.

By presenting both the opportunities and limitations associated with lithium, this thesis aims to offer a balanced perspective on its significant but not unequivocal role in the energy transition. The broader landscape of energy storage solutions continues to evolve, adding layers of complexity to the supply and demand trends for lithium.

CHAPTER 3

Contextualization

The burgeoning demand for batteries, primarily driven by the electric vehicle revolution, has ushered in a new era of strategic emphasis on mineral resources, notably lithium. Portugal, a nation historically not at the forefront of the global lithium narrative, is poised to reshape its national and economic identity in this context. As the predominant lithium producer within the European Union and the possessor of the continent's most significant known reserves - ranking as the 9th largest worldwide as of 2023 - Portugal finds itself in a unique position[33].

Previously, the lithium industry in Portugal primarily catered to the ceramics sector. However, with the surging demand for lithium-ion batteries, there has been a paradigm shift. Portugal aspires not only to expand its extraction capabilities but to establish itself as a global lithium hub, integrating the complete value chain. By harnessing foreign investment, the country is keen on achieving end-to-end expertise - from extraction, refining, cell transformation, battery manufacturing, to the crucial stages of recycling and reusing batteries (Reis et al., 2022).

This ambition offers a unique opportunity, not just for Portugal, but for Europe as a whole. By bolstering its lithium industry, Europe can significantly enhance its autonomy, reducing reliance on imports and, by extension, fortifying its position in the global electric vehicle and energy storage landscape (Reis et al., 2022). This chapter delves into the current landscape of the lithium industry in Portugal, laying the groundwork for readers by offering context before exploring the detailed benefits and challenges associated with the sector.

3.1 Europe’s Position

The European Union (EU) is resolutely moving towards a greener future, aiming for climate neutrality by 2050. A key element of this transition is the transport sector, responsible for roughly a quarter of the EU's CO2 emissions. To address this, the EU has set a target of 30 million electric vehicles on its roads by 2030. Powering these vehicles are lithium-ion batteries, setting lithium as a pivotal element in the Union's green transition (Reis et al., 2022).

[33] USGS. (2023). LITHIUM. In *https://pubs.usgs.gov/periodicals/mcs2023/mcs2023-lithium.pdf*.

However, there is a pressing concern regarding Europe's dependence on external lithium suppliers. As of now, 78% of the EU's lithium imports come from Chile, with the US and Russia providing 8% and 4%, respectively. In an era marked by supply chain disruptions from the Covid-19 pandemic and growing geopolitical tensions, especially with China, such dependence could be perilous. To mitigate this vulnerability and maintain its strategic autonomy, the EU is looking inward. The European Commission's Strategic Plan on Critical Raw Materials, published in September 2020, highlighted the need for Europe to increase its lithium supply by 18-fold by 2030. Recognizing the mineral's importance, lithium has been enlisted as a critical raw material, paving the way for special treatments in the EU's industrial strategy, including subsidies beyond normal EU state aid laws (Reis et al., 2022).

Amidst this lithium-seeking euphoria, Portugal finds itself in an intriguing position. Alongside other European nations like Spain, France, Germany, and more, Portugal possesses lithium reserves waiting to be tapped. The EU's overarching objective, including for Portugal, is clear: secure a sustainable and local lithium supply chain. Many European Member States argue that extracting lithium within European borders, adhering to strict and sustainable criteria, is preferable over sourcing from countries with dubious environmental and social standards (Reis et al., 2022).

Further solidifying Europe's commitment to sustainability, many major battery buyers, from automotive giants to mobile phone manufacturers, are aligning with the EU's vision. These stakeholders are prioritizing a sustainable lithium supply chain. Moreover, aware of the burgeoning battery waste issue in Europe, which currently stands at over 1.9 million tonnes annually, global electric vehicle manufacturers are channeling investments into battery manufacturing and recycling value chains (Reis et al., 2022).

As Europe advances with its green vision, Portugal stands at a crossroads, primed to significantly influence the EU's lithium strategy. With the robust support of the European framework, stringent sustainability standards, and industry-wide collaboration, Portugal is emerging as an essential linchpin in fortifying a more secure and sustainable European lithium supply chain.

3.2 Lithium Regions

Portugal's framework for mineral exploration and exploitation is defined by three types of contracts: prospecting, research, and exploitation. Prospecting and research contracts primarily focus on the discovery of mineral deposits and the determination of their characteristics,

assessing their economic value for potential exploitation. Once a deposit is deemed economically viable, exploitation contracts grant rights to extract the mineral. Regardless of the contract type, environmental impact assessments (EIA) may be mandated, especially considering the location and magnitude of the operation, or if the authorities find it necessary (Reis et al., 2022).

In 2022, as part of Portugal's strategic initiative to explore its rich mineral resources, an international tender was released targeting specific regions with substantial lithium mining potential. The aim was to tap into these reserves, balancing both economic interests and environmental considerations. Detailed below are the eight regions in Portugal that were subjected to this international tender each showcasing unique characteristics and challenges (originally, 11 areas were considered, but three were excluded due to their location within environmentally protected zones).

Serra de Arga

Serra de Arga spans 247.7 km2 and is located in the Viana do Castelo region. This region envelopes municipalities like Caminha, Viana do Castelo, Ponte de Lima, Vila Nova de Cerveira, and Paredes de Coura. Within 3 km of Serra de Arga, there are significant environmental sites like Bertiandos Lagoon, SPA Serra d'Arga, and the Rio Minho. A remarkable feature of this area is its vast expanse of over 10,000 hectares, of which 4280 are recognized under the Natura 2000. Given its environmental significance, the municipalities have expressed reservations against lithium prospecting and mining (Reis et al., 2022).

Seixoso-Vieiros

Covering an area of 243.7 km2 across regions like Braga, Porto, and Vila Real, Seixoso-Vieiros encompasses municipalities such as Fafe, Celorico de Basto, and Mondim de Basto. The newly elected Mayor of Mondim de Basto has highlighted this region as a priority, emphasizing a comprehensive analysis of reports to safeguard both the population and the municipality's interests (Reis et al., 2022).

Massueime

Located in the Guarda region, Massueime occupies 499.7 km2. The history of mining in this region traces back to the early 20th century with minerals like amblygonite, tin, and tungsten being exported. The valley is primarily in the municipality of Pinhel, which has previously

voiced concerns about lithium exploitation affecting urban areas and irrigation (Reis et al., 2022).

Block Guarda-Mangualde, Blocos N E S

This area, encompassing 421.5 km2, lies within the Castelo Branco and Guarda regions, including municipalities like Belmonte and Covilhã. A considerable portion of this block overlaps with the Serra da Estrela Geopark (Reis et al., 2022).

Block Guarda-Mangualde E

With a size of 497 km2 in the Guarda region, this block includes municipalities such as Almeida and Sabugal. Notably, this block also intersects with the Serra da Estrela Geopark (Reis et al., 2022).

Block Guarda-Mangualde W

Stretching across 376.6 km2 in the Guarda and Viseu regions, this block is home to municipalities like Mangualde and Seia. A substantial part of this block lies within the proximity of the Serra da Estrela Natural Park (Reis et al., 2022).

Block Guarda-Mangualde Nw

This block covers 444.9 km2 across Viseu and Coimbra regions, including municipalities such as Viseu and Mangualde. Like other blocks in Guarda-Mangualde, this too has a notable overlap with the Serra da Estrela Geopark (Reis et al., 2022).

Segura

Located in the Castelo Branco region, Segura extends over 311.3 km2. This area includes the municipality of Idanha-a-Nova, which has publicly voiced concerns against mineral prospecting, emphasizing the potential harm to the municipality's developmental strategy. Notably, since 2018, Idanha-a-Nova municipality is part of the International Network of EcoRegions (Reis et al., 2022).

Following a meticulous assessment, it became evident that not all of these regions would be viable for lithium mining operations. The Environmental Strategic Assessment (Avaliação Ambiental Estratégica, AAE) led by the Directorate-General for Energy and Geology (Direção-

Geral de Energia e Geologia, DGEG) delved deep into the specifics of these areas. As a result, out of the eight regions initially identified, two - namely "Arga" and "Segura" - were deemed unsuitable for prospecting and eventual exploitation due to significant environmental restrictions (Government press statement, 2022).

For the "Arga" region, the anticipation of its designation as a Protected Area was a primary reason for its exclusion. Over half of its expanse was considered either off-limits or advisable to avoid, given the potential environmental impact. Similarly, for the "Segura" region, anticipated boundary shifts of the Special Protection Zone of Tejo Internacional led to its exclusion from the list of viable areas (Government press statement, 2022).

For the remaining six regions, urban zones with higher functional and demographic densities were omitted from the prospecting scope. This exclusion led to a significant reduction, shrinking the total area initially up for environmental assessment by 49% (Government press statement, 2022).

Having outlined the specific regions identified for potential lithium mining, it becomes imperative to shift our focus to the ongoing endeavors in this realm. The sites selected after rigorous environmental assessments serve as potential hotbeds for future lithium projects. As Portugal carves its niche in the global lithium industry, understanding the active lithium projects in the country provides insights into the nation's strategic approach, the challenges faced, and the milestones achieved. Let's delve deeper into the current lithium initiatives and their respective stages of development in Portugal.

3.4 Lithium Projects

To comprehend the current state of the lithium industry in Portugal, it's crucial to identify the companies that hold active contracts related to lithium within its borders. While this section won't delve into the intricate details of each company's operations (as that lies beyond the purview of this section), it aims to equip the reader with an overview of the prevailing lithium projects. Here’s a snapshot of these companies and their respective endeavors (DGEG, 2023):

Company	Municipalities	Signature date	Type of contract
Portugal Fortescue, Unipessoal, Lda.	Chaves and Valpaços	10/05/2023	Prospecting and research

Felmica – Minerais Industriais, S.A.	Boticas and Cabeceiras de Basto	14/12/2022	Exploitation
PANNN – Consultores de Geociências, Lda.	Covilhã and Fundão	28/10/2021	Exploitation
Portugal Fortescue, Unipessoal, LDA.	Macedo de Cavaleiros, Mirandela and Vinhais	28/10/2021	Prospecting and research
Lusorecursos Portugal Lithium, S.A.	Montalegre	28/03/2019	Exploitation
Felmica - Minerais Industriais, S. A.	Covilhã and Fundão	24/03/2017	Exploitation
Savannah Lithium, Lda.	Boticas	22/02/2017	Exploitation
Sociedade Mineira Carolinos, Lda.	Guarda	05/10/2015	Exploitation
Felmica - Minerais Industrais SA	Ponte de Lima	10/10/2012	Exploitation
Felmica - Minerais Industrais SA	Boticas	27/6/2008	Exploitation
Felmica - Minerais Industrais SA	Covilhã and Fundão	25/5/2007	Exploitation
Felmica - Minerais Industrais SA	Cabeceiras de Basto, and Boticas	25/5/2007	Exploitation

The data underscores that Portugal has a well-established foothold in the lithium sector. With a strong foundation in place, any subsequent investments would not be venturing into uncharted territory but rather building upon an already robust infrastructure. The ongoing authorizations and sustained corporate interest further accentuate Portugal's strategic significance, suggesting its continued ascent in the global lithium market hierarchy.

3.5 Environmental Cost

In framing the growth of the lithium industry in Portugal, it's essential to highlight the environmental implications of such an undertaking. The nation's pursuit of tapping into the vast reserves of lithium has sparked significant debate, especially in the wake of recent data highlighting the potential environmental ramifications of large-scale lithium extraction.

The research presented by Quercus - Associação Nacional de Conservação da Natureza unveils stark numbers that can't be ignored. If only 10% of the current lithium exploration requests are approved, leading to the establishment of 5 lithium mines, the atmospheric emissions could increase by 8.93 Mt CO2 per annum. To put that in perspective, this figure translates to an increase of 12.6% compared to CO2 emission estimates for 2017. This trend escalates further with the approval of more mines. For instance, should 20% of the lithium exploration requests be greenlit, giving rise to 10 mines, emissions could soar to a staggering 17.86 Mt CO2 per year. This would constitute a 25.3% uptick from 2017's emission estimates (Santos, 2019).

The projected lifespan of these mines, at an average of 23 years, paints a daunting picture in terms of cumulative carbon footprints. Depending on the number of approved mines, the total CO2 emissions could range between 205.45 Mt and 410.91 Mt over the mines' operational periods (Santos, 2019).

The impact of these explorations doesn't only translate to numbers. It holds significant implications for Portugal's commitments under the PNEC 2030 (National Energy and Climate Plan). With an established goal to reduce CO2 emissions, the country aims for a yearly average reduction of 1.29 Mt CO2. However, a single open-pit lithium mine could contribute as much as 1.79 Mt CO2 annually, pushing Portugal further away from its environmental objectives (Santos, 2019).

Moreover, specific mining sites like the Mina de Sepeda, Mina do Barroso, and Mina da Argemela could single-handedly offset the national commitment of annual emission

reduction between 2020 and 2030. To illustrate, the Mina do Barroso alone might release about 2.43 Mt CO2 annually (Santos, 2019).

Given the appealing economic potential of lithium exploration, it's imperative to weigh this against the significant environmental costs underscored by the data. These findings urge stakeholders to take a balanced approach, weighing the immediate benefits against the long-term implications for Portugal's ecological well-being and its commitments to combat climate change. This discourse becomes even more crucial as we venture into subsequent chapters discussing the multifaceted impact of the lithium industry on the nation.

CHAPTER 4

Methodology

This chapter, devoted to articulating the methodology, charts the course through the academic landscapes of research design, data procurement and analysis, and ethical consideration. The selected methodologies seek to weave through secondary data, providing an exploration of the economic, environmental, and social vertices of lithium exploration within the Portuguese context.

4.1 Research Design and Approach

This investigation, navigating through the intricate landscapes of lithium exploration in Portugal, adopts a descriptive research design, with a keen focus on the Boticas mine, operated by Savannah Resources. The locus on this specific mine is not arbitrary but is informed by its noteworthy impact and stature within the national framework of lithium projects in Portugal. Recognizing its prominent role and the richness of available secondary data, the study anticipates that a detailed, granular exploration of the benefits and challenges experienced at Boticas will not only provide depth to the analysis but also enable a nuanced understanding of larger, scalable impacts at a national level.

4.2 Data Collection and Analysis

The investigational lens of this study sifts through a plethora of secondary data, comprising governmental reports, academic publications, industry datasets, and international agency findings pertinent to lithium exploration in Portugal.

In navigating through the analysis, this research employs a systematic approach to dissect the multifaceted impacts and challenges encapsulated within the collected data. Utilizing statistical and thematic analysis tools, the data is scrutinized, with the economic impacts, environmental considerations, and social implications being analyzed and juxtaposed to present a holistic, empirically grounded narrative of the benefits and challenges entwined with lithium exploration within the Portuguese context. The synthesis of these findings subsequently forms the bedrock upon which subsequent discussions and conclusions are anchored.

4.3 Limitations

This research, acknowledges certain limitations inherent to its design and execution. Primarily, the exclusive reliance on secondary data restricts the analysis to pre-existing information, potentially limiting the scope and contemporaneity of the insights obtained. Furthermore, the focus on the Boticas mine, whilst providing a detailed and granular viewpoint, may introduce biases or particularities unique to this specific context, which may not universally apply across different mining projects within Portugal. Additionally, the extrapolation of findings from the Boticas mine to a national scale, though informed and considered, must be interpreted with caution given the potential variability in regulatory, environmental, and social contexts between different regions and projects. Thus, while the insights derived offer a valuable lens through which to view the broader narrative of lithium exploration in Portugal, the aforementioned limitations offer boundaries that circumscribe the applicability and generalization of the findings presented herein.

CHAPTER 5

Results

The exploration and exploitation of lithium, a critical raw material, have emerged as pivotal elements in understanding Portugal's socio-economic and environmental tapestry. Particularly, the exploration of the Boticas mine by Savannah takes center stage in our investigation, serving as a tangible case study that enables us to navigate through the multifaceted landscape of the nation's lithium industry. Our insights, derived from a focused examination of the Boticas mine, seek to provide a robust framework to understand and extrapolate the findings to Portugal's broader lithium exploration and extraction endeavors.

In this chapter, the obtained results and subsequent findings offer an in-depth look into the benefits and challenges surfacing from lithium exploration and mining, shaping a dialogue that is both locally significant and nationally relevant. Boticas, while being a focal point, acts as a catalyst, propelling our discussion forward to evaluate the potential impacts, both positive and negative, that the lithium industry could imprint upon Portugal's economy, environment, society, and strategic positioning in global supply chains.

As we weave through the upcoming sections, detailed analyses and discussions will unveil the complexities and implications that loom within the lithium industry, anchoring our observations at Boticas and elevating our discourse to a nationwide context. The intention here is dual-fold: to provide a thorough exploration into the realities and potentials harbored by the Boticas mine, and subsequently, to extrapolate these insights, ensuring they reverberate through the broader contours of lithium exploration across Portugal.

Thus, we embark on a journey, wherein the specificities of the Boticas mine converge with the overarching narrative of Portugal's lithium industry, forging a pathway that guides us through the intricacies and wider implications this sector holds for the nation's future.

5.1 Benefits

Navigating through the labyrinthine trajectories of mineral exploration and its multifarious impacts, the advent of the Boticas mine by Savannah extends a spectrum of potential benefits that portend substantive impacts across numerous domains in Portugal. This exploration heralds the amplification of economic, environmental, and social paradigms, weaving a tapestry of opportunities and positive augmentations. In the ensuing discourse, we shall delineate into six cardinal categories of benefits, each underpinning the holistic impact

envisaged by the project. The exploration of these benefits, ranging from economic enhancements to strategic advantages, underscores not merely the immediate impacts but also germinates a discussion regarding the sustainable and strategic upliftment of the region and the nation at large.

The analysis of these benefits, while concurrently situated within a framework that recognizes and anticipates prospective challenges, facilitates a balanced and perceptive exploration into the comprehensive scope and anticipated path of the Boticas mine exploration. It's pivotal to underscore that while the Boticas mine serves as a focal point of study, the insights derived permeate beyond its geographical and operational confines, influencing and informing the broader narrative of lithium exploration across Portugal. This endeavor to juxtapose specific findings from Boticas with the generalized milieu of the nation's lithium industry enables the extrapolation of conclusions and considerations that potentially reverberate through the entirety of the country's mineral exploration and exploitation landscape, shaping policies, strategies, and practices in the coherent and sustainable development of the lithium industry nationwide.

Economic and Financial Benefits

The exploration of the Boticas mine unfolds a substantial economic and financial tapestry, intrinsically weaving a plethora of benefits into Portugal's lithium industry and beyond. With the Boticas mine housing the most significant spodumene lithium resource in Western Europe (Savannah, 2023), its strategic economic value is notably prominent, cementing a foundation upon which remarkable financial projections are built. A glance at these figures elucidates a capital expenditure of USD 236M, coupled with a post-tax NPV8% of USD 953M, and an IRR post-tax of 77.3%. Furthermore, the project predicates a post-tax payback period of merely 1.3 years (Savannah, 2023).

In the realm of initial investments, a commitment of 98.1 million euros is mapped out, alongside an estimated revenue projection of 1,420 million euros. The EBITDA is notably pegged at 738 million euros, and the net present value before taxes ascends to 327 million euros. This financial influx is not confined to the project but percolates into the broader economic landscape, with a contribution to GDP estimated at 65 million euros in the investment phase and 34 million euros per year during the operation phase. Furthermore, a projected impact on supply sectors is substantial, expecting to impart a 1,161 million euros influence on gross output in related sectors (Carballo-Cruz et al., 2020).

A pivotal piece in the economic puzzle is the support rendered to the burgeoning EV Market. The annual production of lithium from the Boticas mine is slated to be sufficient for approximately 0.5 million electric vehicle battery packs (Savannah, 2023), thus, not only enriching the national economic framework but also providing robust support to an industry that is pivotal in navigating the pathways towards a sustainable future.

An emphasis on export also threads through the economic narrative with 86% of production intended for export, thus positively influencing national exports in metallic ores and related products. It's imperative to highlight the public revenue generation as well. With contributions enveloping company profits, wages, security contributions, royalties, and other taxes, the project promises to inject millions of euros per year into public coffers (Carballo-Cruz et al., 2020).

Local businesses and residential construction industries are also poised to witness a potential economic uplift, thus broadening the financial impact spectrum. Furthermore, the exploration and development activities are backed by a significant economic investment and development, with €34.5 million already invested and a projection of at least €110 million more to be invested, elucidating the depth of financial commitment and economic reverberation (Savannah, 2023).

Conclusively, the job creation metric is indispensable in evaluating the economic stratagem. Over 300 jobs are expected to be forged during the construction phase and an additional 200 during the operational phase, alongside a cascade of indirect employment opportunities (Carballo-Cruz et al., 2020).

In summary, the economic and financial benefits stemming from the Boticas mine exploration by Savannah are poised to resonate through various sectors and layers of the Portuguese economy, creating a multi-faceted impact that enriches both the immediate and extended economic landscape.

Environmental and Sustainability Benefits

The lithium extraction project in Boticas is not only a venture immersed in economic prospects but also one that casts a mindful eye towards environmental and sustainability considerations. At its core, the project harbors an unwavering commitment to carbon neutrality, with a clear target that underscores its dedication to mitigating the pervasive global challenge of climate change.

Delving into the decarbonization agenda, the project envisages future plans that pivot towards further decarbonizing its operations, thus aligning itself with a trajectory that not only fulfills current sustainability metrics but also evolves alongside future advancements and requirements. This strategic alignment does not operate in isolation but also robustly supports the European Union's (EU) overarching energy transition goals, contributing towards the strategic milestone of achieving carbon neutrality across the EU by 2050 (Savannah, 2023).

An indispensable component of this environmental strategy is the lithium produced at the Boticas mine, which plays a pivotal role in eliminating substantial CO2 emissions in the European transport sector. Specifically, the lithium, instrumental in battery production, could potentially help eradicate 100Mt of CO2 emissions, offering a tangible and impactful contribution to the larger global carbon reduction endeavors (Savannah, 2023).

Moreover, the project melds innovation with its environmental stewardship through the integration of novel measures such as implementing a sensor network meticulously designed to monitor various environmental parameters. This not only ensures the adherence to environmental standards but also enables real-time adaptability and response to any environmental contingencies, safeguarding the ecological balance of the operational vicinity (Savannah, 2023).

Furthermore, the endeavor into lithium exploration in Boticas directly aligns with the European Commission's climate objectives, offering a complementary pathway that not only facilitates but also fortifies the Commission's mitigation efforts against climate change.

In a bid to achieve net-zero emissions for Scope 1 and 2 emissions over the project's lifespan, the environmental considerations embroidered into the Boticas mine exploration narrative are both progressive and pivotal. They not only underscore a commitment to environmental stewardship but also elucidate a path that intertwines economic prosperity with sustainability, framing a model where environmental care and industrial progression are not mutually exclusive but collaboratively enriching (Savannah, 2023).

In sum, the exploration of the Boticas mine emerges as a beacon of harmonizing economic development with environmental and sustainability benefits, offering a blueprint that navigates the delicate balance between industrial progression and ecological preservation.

Strategic and Supply Chain Advantages

The exploration of the Boticas mine unveils a panorama of strategic and supply chain advantages, mapping out a trajectory that not only fortifies national economic frameworks but also intertwines with the tapestry of the European strategic material landscape.

Anchoring itself in the realm of strategic significance, the Boticas mine positions Portugal within the crucial narrative of lithium supply, notably within the European context. The project aspires to harness lithium in quantities substantial enough to produce approximately 0.5 million electric vehicle (EV) battery packs on an annual basis (Savannah, 2023), sculpting a path that paves the way for Portugal to be at the epicenter of the European lithium battery supply chain.

Zooming out to a continental perspective, the project aligns with the projections of the European Commission regarding the imperative for lithium. With an estimated need for lithium ballooning to 18 times more by 2030, and an astronomical 60 times by the ensuing two decades, the strategic lithium resource exploration in Boticas stands as a timely and pivotal initiative (Savannah, 2023).

Furthermore, the mine exhibits a coherent alliance with the EU's carbon neutrality goal by 2050, contributing to a future where strategic materials are sourced with an eye on environmental and sustainability imperatives.

In this strategic tableau, the Boticas mine is more than a domestic project, it acts as a catalyst propelling Portugal into a central role within the European lithium battery supply chain, amplifying its influence and strategic importance on the continent. Furthermore, it converges with the goals of the European Union in sourcing a minimum of 10% of critical raw materials, like lithium, domestically (Savannah, 2023).

The exploration of lithium, designated as a Strategic and Critical Raw Material in the proposed EU Critical Raw Materials Act, not only dovetails with the legal and strategic frameworks but also enhances the battery value chain. Thus, it stimulates various facets of Portugal's value chain, reinforcing the global battery production ecosystem, and downstream activities for mineral transformation, while simultaneously cultivating additional equivalent annual duration jobs, spurring both economic and strategic growth.

Moreover, the strategic advantages are not limited to merely the extraction and production stages but permeate the entire supply chain. Savannah, with its 100% ownership of the project since 2019, has maneuvered into additional exploration areas with the addition of the Aldeia Mining Lease Application, envisioning a scope that expands beyond immediate

horizons and entrenches its strategic position in the lithium exploration and supply sector (Savannah, 2023).

Hence, the Boticas mine, under Savannah's aegis, unfurls as a node of strategic and supply chain prowess, weaving an intricate narrative that melds national aspirations with continental ambitions, crafting a path that strategically navigates through the evolving demands and landscapes of the lithium industry.

Legal, Compliance, and Ownership Advantages

In navigating the intricate labyrinth of lithium exploration at the Boticas mine, a spectrum of legal, compliance, and ownership advantages has surfaced, wielding a critical role in securing, safeguarding, and stabilizing the strategic path charted by Savannah in Portugal's lithium domain.

Embarking on this exploratory venture, the Boticas mine project radiates a demonstrable adherence to the regulatory landscape, possessing a 30-year Mining Lease awarded in 2006, which not only provides a foundational legal stability but also confers a long-term vision and commitment towards the lithium exploration initiative in Portugal. Ensuring a streamlined progression of its operations, Savannah has also engaged in continual interaction with the Portuguese Environment Agency (APA), reflecting a structured approach towards regulatory compliance and addressing environmental and socio-economic concerns (Savannah, 2023).

In addition, the Positive Environmental Impact Statement (DIA), issued by APA on May 31, 2023, bespeaks a confluence between the project's ambitions and regulatory assent, where conditions, measures, and compensations agreed upon by Savannah ensure a responsible developmental trajectory that aligns with regulatory guidelines and standards, and exhibits an exemplary adherence to environmental and socio-economic responsibility and compliance.

The Boticas mine project is not just a venture of economic potential but is enmeshed within a broader tapestry of legal and strategic frameworks, notably the EU Critical Raw Materials Act, which designates lithium as a Strategic and Critical Raw Material. This alignment not only legitimizes the project’s utility on a continental scale but also enmeshes its operations within the strategic imperatives of the European Union, thereby ensuring a syncretism between localized operations and regional strategic material narratives.

In essence, the interplay of legal compliance, strategic alignment with EU directives, and the cohesive ownership by Savannah coalesce to form a robust framework that not only

undergirds the Boticas mine exploration with stability and compliance but also ingeniously integrates it within the broader strategic and legal narratives, both on a national and European scale.

Social and Community Benefits

The exploration of the Boticas mine has ignited a cascade of social and community benefits that weave into the multifaceted tapestry of local and regional development in Portugal. Illuminating the dimensions of social progress and community engagement, the exploration underscores a robust framework that navigates through job creation, economic uplift, and strategic community interventions.

The endeavors of the Boticas mine project crystallize into tangible opportunities for job creation and employment, thereby infusing vitality into the local economic framework. In the construction phase, 300 jobs are forged, followed by an enduring 200 jobs in the operation phase, effectively securing livelihoods and enhancing economic stability in the locale. The creation of additional equivalent annual duration jobs during both phases fortifies this impact, cascading it through various sectors and regions (Carballo-Cruz et al., 2020).

The robust economic uplift further spirals into various social and community domains, impacting local income through a myriad of streams which include wages, services, local taxes, and company transfers. The potential to rejuvenate local demographics, by possibly increasing the birth rate and reinforcing population stability through project development and supporting public policies, aligns the exploration with longer-term social sustainability objectives (Carballo-Cruz et al., 2020).

In a delicate interplay with community development, the project synthesizes a Community Development Fund, thereby financing medium and long-term capacity-building and skill enhancement measures, which are instrumental in nurturing local talent and fostering a skillful workforce. Furthermore, the enhancement of infrastructures, particularly in accessibility and mobility for local communities, provides a foundational pillar that not only supports mining activities but also progressively benefits the societal and economic milieu of the community (Carballo-Cruz et al., 2020).

In an embrace of community support and engagement, a foundation has been established to receive €0.5 million annually, acting as a conduit for investment in local projects and activities. Alongside, the "Sharing" and stakeholder engagement programs have been

active since 2017, thereby channeling funds and support into various local initiatives, forging a symbiotic relationship between the project and the community (Savannah, 2023).

Through a lens that blends social and economic prosperities, the Boticas mine exploration emerges as not just a mining endeavor but a catalyst for social and community development. The intertwined narratives of job creation, economic uplift, and active community engagement and development craft a scenario where the exploration not only extracts lithium but infuses prosperity, stability, and growth into the socio-economic veins of the local and extended communities.

Industry Development and Strategic Importance

On the forefront of industry development, Boticas mine exploration resonates with the potential for enhancing the battery value chain, distinctly within Portugal, thereby galvanizing global battery production ecosystems and downstream activities for mineral transformation. Moreover, the exploration heralds a possible surge in various phases of the value chain, progressively positioning Portugal at the epicenter of the European lithium battery supply chain (Savannah, 2023).

The strategic importance of lithium, designated a critical raw material in the EU since 2020 (Simões, 2020), propels the Boticas mine exploration into a pivotal role amid a burgeoning demand, especially pertaining to Li-ion batteries, which are indispensable in the emerging electric vehicle (EV) market. Notably, the project aims to produce lithium sufficient for approximately 0.5 million EV battery packs annually, carving a pathway to impactfully cater to the European Commission's estimated 18x more lithium need by 2030 and a staggering 60 times more by 2050. This anticipated increase in lithium demand by 2050, especially in Europe, frames the exploration as a cornerstone in a rapidly evolving market (Savannah, 2023).

Zooming out to a broader perspective, the strategic exploration of the Boticas mine tangentially facilitates the development of national and European industries. The government of Portugal harbors aspirations of retaining within its borders all lithium value chain elements, encompassing mining, processing, and recycling, thereby creating a self-sustaining, circular lithium industry. This is fortified by the European Union's grant of 3.2 billion euros for lithium battery projects across seven Member States under the Important Project of Common European Interest (IPCEI) (Simões, 2020).

Navigating through the waters of innovation and research, particularly in lithium recycling under a circular economy framework, Portugal accentuates an integrated industrial

approach, which encapsulates extraction, processing, and recycling of lithium, aiming to ripple innovations and sustainability through the lithium industry. Moreover, the strategic emphasis on keeping the entire lithium value chain within the nation anchors industry development while concurrently propelling Portugal into a potentially pivotal position within the European lithium supply ecosystem.

In synthesis, the Boticas mine, beyond its extractive functionality, emerges as a harbinger of strategic industry development, elegantly entwining Portugal into the larger narrative of the European lithium industry and strategically positioning it as an essential player in the evolving tapestry of lithium demand, supply, and sustainability.

5.2 Challenges

Navigating through the extensive lattice of benefits realized through the exploration of the Boticas mine, it is equally paramount to examine the array of challenges interspersed within this intricate venture. The comprehensive exploration and subsequent extraction processes in lithium mining, particularly in a geographically and environmentally sensitive area like Boticas, demand an exhaustive analysis across several dimensions. This section will delve into six pivotal types of challenges: Economic, Environmental, Legal & Regulatory, Operational, Social, and Global Market Challenges, each presenting its unique set of hurdles and potential implications.

While the economic advancements and energy transition facilitated by lithium extraction are significant, it is the ethical obligation of scholars and industry professionals alike to scrutinize the intricacies of the operational hurdles, environmental impacts, social perceptions, and global market fluctuations. This ensures not only a sustainable approach towards lithium mining but also facilitates a balanced discourse, providing stakeholders with a holistic view of the operations at the Boticas mine.

Considering the diverse facets of these challenges, we engage in an exploration to unravel the complexities and potential cascading effects each challenge might impose on the exploration activities, local communities, and the broader economic and environmental landscape. This thorough examination does not merely stem from a perspective of identifying problems but is a pursuit to underline areas requiring strategic interventions, informed decision-making, and potentially, the development of innovative solutions to navigate through the intricacies embedded in the lithium industry in Portugal.

In ensuing sections, each type of challenge will be dissected, providing a detailed exploration of their components, relevance, and potential ramifications, firmly rooted in the context of the Boticas mine, thereby offering a substantive foundation upon which informed, equitable, and sustainable mining practices may be forged.

Economic Challenges

The exploration and potential exploitation of the Boticas mine by Savannah unfolds a series of intricate economic challenges, reflecting the opaque and often convoluted nature of the global lithium market. An immediate challenge encountered is the obscure pricing mechanisms inherent to the lithium market, with prices, shrouded in relative ambiguity, often being determined by a myriad of fluctuating factors, further complicated by the absence of a standardized global pricing model. Lithium, a critical component in the propulsion of sustainable technologies, finds its value often dictated through obscure and privately conducted transactions, complicating the precise prediction of return on investment and economic viability (Savannah, 2023).

Coupled with the opacity of pricing, the bulk of lithium material transactions are shrouded within the confines of long-term contractual agreements, where prices are subject to adjustment based on a plethora of variables, ranging from market demand, geopolitical stability, to technological advancements in extraction and processing technologies. This, in turn, infuses a level of unpredictability into the economic forecasting of lithium mining enterprises, demanding robust and adaptive financial strategies to navigate through the fluctuating economic waters (Savannah, 2023).

As we delve deeper into the economic intricacies of the Boticas mine exploration, it becomes evident that the challenges are not only rooted in the market dynamics but are also significantly influenced by the contractual and price adjustment methodologies employed within the industry. Thus, understanding and maneuvering through the economic challenges becomes an indispensable component in not merely ensuring the financial viability of the lithium extraction but also in stabilizing and securing a sustainable trajectory in the economic landscape of the lithium industry in Portugal, and by extension, the global market.

In conclusion, the economic challenges affronting the lithium mining industry, particularly exemplified in the Boticas mine exploration, necessitate not only a deep understanding of the prevailing market dynamics but also call for innovative and resilient economic strategies that can accommodate the inherent fluctuations and variables embedded

within the lithium market. This ensures that the economic backbone of such exploratory and extractive ventures is not only solidified but is also capable of sustaining the overarching objectives and ethical considerations integral to modern mining activities.

Environmental Challenges

Embarking upon a journey through the verdant landscapes of Boticas, where the tapestry of natural beauty and agricultural heritage intertwines with the innovative spirit of lithium exploration by Savannah, we encounter a myriad of environmental challenges that demand our discerning attention. The robust recognition by the FAO, classifying the region as a World Agricultural Heritage site, amplifies the necessity to navigate the intricacies of lithium mining with utmost environmental sagacity.

The juxtaposition of fostering technological and economic advancement with the imperative of safeguarding the environment unfolds a challenging narrative. The inevitable environmental footprint of mining, even when endeavored with the best practices, casts a shadow of concern, specifically regarding the impact on the region's lauded landscapes and its subsequent reverberations on local agriculture and biodiversity.

Moreover, the ethically and logistically challenging domain of waste management comes to the fore, bearing questions regarding the sustainable and responsible disposal of mining waste, such as washery rejects[34]. The quintessential challenge lies in ensuring that the methodologies employed do not merely adhere to regulatory benchmarks but also resonate with a deeper ethical and sustainable resonance, safeguarding both immediate and future ecological integrity.

Furthermore, the availability and management of water resources, particularly during periods of drought, magnify the potential environmental impact, especially upon the delicate ecosystems of the Covas river[35]. The intricate balance between ensuring adequate water supply for mining operations, while sustaining the ecological and community needs, engenders a complexity that requires a meticulous and sustainable approach.

Thus, the exploration of the Boticas mine becomes a delicate ballet of balancing economic and technological pursuits with steadfast commitment to environmental stewardship.

[34] Zero. (2023, April 19). *ZERO alerta para 6 pontos negativos na exploração de lítio no Barroso*. https://zero.ong/noticias/zero-alerta-para-6-pontos-negativos-na-exploracao-de-litio-no-barroso/

[35] Ibid

The challenges encompass not only the preservation of physical landscapes but also safeguarding water resources, managing waste sustainably, and ensuring that the ecological, as well as societal, footprints of mining are mitigated, if not entirely neutralized. This endeavor, thus, unfolds a tapestry where the threads of economic progress, technological advancement, and environmental integrity must be woven with discerning care and foresight.

Legal and Regulatory Challenges

Venturing into the realm of the Boticas mine exploration in Portugal, the intertwining paths of legal and regulatory adherence lay down a complex labyrinth to be navigated by Savannah. The diligent journey through legal frameworks and regulatory compliances signifies a commitment not only to lawful operations but also to fostering an environment of ethical and sustainable mining practices, thereby safeguarding the multifaceted interests of environmental and societal stakeholders.

Legal and regulatory challenges permeate through various aspects of the exploration, from the meticulous adherence to licensing processes to compliance with environmental directives. The initial hurdles appear in the form of licensing, where the strict and comprehensive processes ascertain that the exploration aligns with both local and national regulatory benchmarks. Subtle, yet crucial, is the task to ensure that every step of the operation, from initial exploration to potential extraction, adheres unwaveringly to these licensing protocols (Savannah, 2023).

Simultaneously, awaiting approval from Portugal's environmental regulator and ensuring unwavering compliance with Environmental Impact Assessment (EIA) study directives delineate another layer of the regulatory journey. The EIA, an essential compass guiding the environmental feasibility and impact of the project, demands not only thorough investigation and documentation but also an adherence to resultant directives, entailing possible design alterations and strategic modifications to align the project with environmental norms and standards (Savannah, 2023).

Proliferating through the legal framework, the intricate dance with regulatory authorities and processes extends further. The lengthy approval process, extending from the initial submission in May 2020 to an anticipated Environmental License issuance in 2024, presents an exhaustive timeline, reflecting the complexity and depth of scrutiny embedded within the regulatory pathway. Moreover, the incorporation of Declaration of Environmental Impact (DIA) conditions into the final project design heralds additional complexities and

probable design recalibrations, ensuring that every facet of the project pulsates with regulatory and environmental coherence (Savannah, 2023).

Notably, the public consultation periods, although vital for democratic and inclusive decision-making, infuse additional variables into the regulatory journey. Balancing the valuable input and concerns of the public with the logistical and economic frameworks of the project becomes an indispensable task, ensuring that the resultant exploration not only adheres to regulatory and legal frameworks but also resonates with the concerns and aspirations of the societal landscape it seeks to inhabit.

In light of the aforementioned, the legal and regulatory path of the Boticas mine exploration, whilst intricate and demanding, unfolds as a testament to the intrinsic balance between technological progress, environmental stewardship, and societal integrity, ensuring that the explorative venture is not only lawful and compliant but also ethically and environmentally attuned.

Operational Challenges

Embarking upon the exploration of the Boticas mine, the operational challenges unfold as a multifaceted puzzle, providing both hindrances and opportunities for Savannah to navigate through. These challenges, embedded within the technical and logistical facets of mining operations, necessitate a confluence of strategic foresight, technical acumen, and robust planning to ensure that the exploration not only realizes its economic potential but also adheres to the highest standards of safety, efficiency, and environmental stewardship.

One of the pivots upon which the operational efficiency of the mine exploration hinges is managing technical risks. The New Scoping Study of 2023 indicates a relatively low technical risk; however, the traditionally varied and unforeseeable challenges intrinsic to mining operations must not be underplayed. From ensuring that the processing plant proficiently produces spodumene concentrate at a determined 5.5% Li2O grade to safeguarding against potential issues related to mining depth, equipment, and geological variances, the technical aspect demands continuous oversight, adaptation, and preparedness (Savannah, 2023).

Moreover, the pivotal aspect of translating offtake and investment interests into formal agreements underlines an essential operational challenge. The meticulous conversion ensures not only the financial and logistical stability of the project but also establishes a structured framework for the mine's products to seamlessly integrate into the wider market. The necessity

to secure a varied palette of offtake partners for different products - including lithium concentrate, quartz, and feldspar - unfolds as a challenge that demands strategic alignment with market demands, competitive pricing, and maintaining quality assurances (Savannah, 2023).

Navigating through the operational pathway, the exploration and mining risks owing to the largely underexplored wider project area introduce a further layer of complexity. The imperative to ensure that exploration effectively maps and validates the geological and economic viability of the wider area, whilst managing associated risks, becomes paramount.

Furthermore, the intricacies of adhering to and ensuring safety, particularly in the disposal and management of tails from the processing plant, require meticulous planning and implementation. Ensuring that the methodologies employed for tailings, which are thickened and dry stacked, are not only efficient and safe but also negate the necessity for a tailings dam, underscores a vital operational and environmental consideration.

In navigating through these operational challenges, the exploration of the Boticas mine becomes not only a venture of economic and technological progression but also a meticulous ballet of balancing technical, logistical, and market-oriented challenges with steadfast commitment to environmental and societal coherence.

Social Challenges

Diving into the exploration of the Boticas mine, social challenges surface as a pivotal component, intertwining the technical and economic facets of the project with the societal tapestry of the region. These challenges, resonating through the realms of public perception, stakeholder involvement, and community dialogue, weave a complex scenario where Savannah needs to strategically and empathetically engage with the social and cultural milieu in which the exploration is enmeshed.

The fabric of public perception, delicately interwoven with environmental concerns and potential impacts on local communities, necessitates a nuanced and continuous engagement from Savannah. Crafting and maintaining a positive public and stakeholder perception while simultaneously navigating through potential opposition due to environmental concerns become paramount. This involves not only transparent and continuous communication regarding the exploration’s impact and mitigation strategies but also ensuring that the operational facets of the mine are visibly and tangibly aligned with ethical and sustainable practices.

Moreover, stakeholder involvement extends as a crucial strand within the social challenges. The imposition of a Benefit Sharing Plan and Good Neighbor Plan, though

potentially beneficial in sharing the economic and infrastructural fruits of the exploration, require careful and inclusive negotiation. Beyond mere imposition, ensuring a participatory process that allows for tangible and meaningful input from local communities into long-term local development strategies becomes crucial. This encompasses not only the direct impact of the mining operation but also how it interfaces with the broader societal, environmental, and economic landscapes of the region[36].

Simultaneously, fostering and maintaining an open, respectful, and continuous community dialogue stand forth as an essential task. This is not merely confined to addressing the concerns and inputs from local communities, but also ensuring that these dialogues tangibly influence the exploration's strategies and operations. Ensuring that attention is given to residents' quality of life, not just in terms of direct economic or infrastructural impact but also considering the subtler impacts on societal and cultural aspects, is vital[37].

Through this lens, the absence of long-term strategic planning, especially in ensuring regional development and improved living conditions, reflects a potential social criticism. Crafting, communicating, and implementing a strategic plan that not only addresses the immediate and tangible impacts of the exploration but also integrates it within a longer-term vision for the regional development becomes an integral element of navigating through the social challenges.

Thus, in the journey through the social landscape of the Boticas mine exploration, the pathways of public perception, stakeholder involvement, and community dialogue intertwine. Here, Savannah is not merely an explorer of geological landscapes but also a navigator of the social and cultural terrains, where the exploration becomes a chapter within the wider narrative of the region’s societal and economic journey.

Global Market Challenges

Navigating through the intricate waters of the global market, the exploration of the Boticas mine is subject to a complex array of challenges that intertwine the local operational realities with the fluid dynamics of international lithium markets. The domain of global market challenges encompasses demand fluctuations, pricing volatilities, and international economic

[36] Zero. (2023, April 19). *ZERO alerta para 6 pontos negativos na exploração de lítio no Barroso*. https://zero.ong/noticias/zero-alerta-para-6-pontos-negativos-na-exploracao-de-litio-no-barroso/

[37] Ibid

landscapes, each casting its own unique set of considerations and hurdles upon the exploration project.

At its core, the susceptibility to demand fluctuations in the global market underscores a critical challenge. The nuances of the lithium market, subject to influences from global market conditions, present a variable and often unpredictable landscape wherein the demand and prices for lithium can oscillate due to myriad factors ranging from geopolitical considerations, technological advancements, to global economic health (Simões, 2020). Given the potentially volatile nature of lithium demand and pricing, crafting a strategic approach that not only navigates through these fluctuations but also safeguards the economic viability of the exploration becomes paramount.

Further extending into the global domain, the economic and market dynamics, particularly the uncertainties around lithium price evolution, functioning of the market, and various market players, introduce another layer of complexity. The lithium market, characterized by its lack of an organized exchange and frequent reliance on bilateral contracts, demands a nimble and strategic approach to navigate through its distinctive challenges. Managing and strategizing around the potential decoupling in price trends between different lithium compounds, such as LiOH and Li2CO3, due to shifting global demands, unfolds as a nuanced challenge requiring attentive market analysis and strategic planning (Simões, 2020).

Within this framework, global competition and comparative analysis become notably intricate due to the lack of standardized reporting formats across the global landscape. This complicates the ability to perform a coherent and comprehensive competitive analysis, further amplifying the challenges of positioning the lithium from the Boticas mine effectively and competitively within the global market (Simões, 2020).

In embracing these global market challenges, Savannah ventures into a dynamic that is not only rooted in the tangible and technical realities of mine exploration but also intricately entwined with the fluid and often unpredictable dynamics of the global lithium market. Through this lens, the exploration of the Boticas mine becomes not only a journey through geological and operational landscapes but also a voyage through the multifaceted and dynamic tapestry of global market challenges.

5.3 Mapping Findings to Research Questions

Navigating through the specific case of the Boticas mine allows us to draw critical insights and derive particular conclusions which can be extrapolated and considered within the broader

national context of Portugal. The examination of economic, environmental, and social trajectories in the Boticas mine establishes a potent foundation from which to respond to the research questions, steering them towards a wider scope of understanding that encompasses nationwide implications and strategies.

“How do the multifaceted economic impacts of lithium exploration in Portugal, including aspects like GDP, exports, and job creation, influence national and regional economic development, and what can be projected regarding its sustainable impact on the economy?”

The Boticas mine delineates a pronounced economic boost through robust investment, job creation, and promising revenue projections within its locality. Extrapolating this, lithium exploration in Portugal could invariably become a crucial economic catalyst nationally. By potentially enhancing GDP, contributing significantly to exports through the production and sale of lithium, and generating employment, lithium exploration projects could indeed propagate regional and national economic vibrancy.

However, the long-term sustainability of these economic impacts intersects with myriad factors, including market demand, technological advancements, regulatory frameworks, and global economic climates. Furthermore, the balancing act of ensuring economic propulsion does not cascade into detrimental environmental and social effects is imperative. Therefore, on a national level, a structured, adaptable, and forward-thinking strategy that encompasses not only economic but also ethical and ecological considerations is crucial to ensure the sustainability of economic benefits derived from lithium exploration.

"How do the challenges faced in environmental, social, and regulatory domains impact the feasibility and sustainability of lithium projects in Portugal, especially concerning regulatory adherence and promises of social and ecological betterment?"

Insights from the Boticas project highlight a symbiotic relationship between environmental, social, and regulatory challenges and the overall feasibility of lithium projects in Portugal. The intent and commitment towards carbon neutrality and decarbonization, juxtaposed against potential environmental and social upheavals, underscore a multifaceted challenge that extends beyond operational and financial considerations.

In a nationwide context, the manifestation of these challenges could potentially permeate various lithium projects across Portugal, wherein the fulfillment of regulatory

compliances, social promises, and ecological commitments becomes pivotal in determining the overall feasibility and sustainability of the projects. The ethical onus extends beyond mere adherence to regulatory frameworks, embedding deeply into transparent, inclusive, and responsible practices that discernibly mitigate environmental and social impacts. This establishes that the feasibility of lithium projects on a national scale is holistically interwoven with the authentic, tangible delivery of promises related to social uplift, ecological safeguarding, and sustained economic benefit.

Culminating from the above reflections, the subsequent chapters will distill conclusions and formulate recommendations that harmonize the economic aspirations with conscientious and responsible practices within the national domain. Striving to engineer a framework that holistically integrates economic, environmental, and social facets, the forthcoming discussions will aspire to carve a pathway that substantively respects and enhances the multidimensional landscapes traversed by lithium exploration in Portugal.

CHAPTER 6

Conclusions and Recommendations

In a nexus where economic propellants entwine with multi-faceted challenges, Portugal's venture into lithium exploration and production has curated a tapestry of opportunities and complexities. Through a meticulous examination of the economic, environmental, and social vectors presented in the preceding chapters, this thesis underlines the pivotal role of lithium exploration in advancing not only Portugal's economic frontier but also its alignment with evolving global energy paradigms.

Navigating through the tapestry of findings, the first research question prompts an exploration into the multifaceted economic impacts emanating from lithium exploration in Portugal. Indeed, the vitality of lithium exploration has proven to be a formidable lever in augmenting both national and regional economic landscapes, infusing tangible vitality across various economic vectors including, but not limited to, GDP augmentation, catalyzing employment, and bolstering exports. The exploration and consequent production of lithium have not only anchored existing economic structures but have also gently nudged the nation towards a trajectory that aligns with global renewable energy and electric vehicle trends, thereby embedding it within a larger, forward-moving economic narrative. However, as underscored through various instances within the thesis, the aura of this economic vitality is not without its ephemeral undertones. The sustainability of these economic benefits remains invariably tethered to an intricate web comprising global lithium demand, advancements in lithium extraction and processing technologies, and the perpetuation of domestic and international investments in Portugal's lithium exploration and production infrastructures. Thus, while the immediate economic impacts present a luminous picture, the shadows of uncertainty concerning its longitudinal sustainability linger, precipitating a cautious optimism that must invariably guide future explorations and policymaking.

In addressing the second research question, this thesis traversed the landscapes of challenges embedded within the environmental, social, and regulatory contexts of lithium exploration projects. The interconnectedness of these challenges has proven to not merely be hurdles to be navigated but have sculpted a terrain that intimately influences the feasibility, sustainability, and overall lifecycle of lithium projects within Portugal. Environmental considerations, social impacts, and regulatory adherence have emerged, not as isolated challenges, but as a collective entity that molds the contours of project implementation, community acceptance, and sustainability. The embeddedness of these projects within local

ecosystems, both ecological and social, underscores a pivotal realization: the viability and acceptability of lithium projects are invariably linked to their capacity to navigate, mitigate, and where possible, enhance these domains, ensuring that the pursuit of economic aspirations does not inadvertently erode the ecological and social fabrics that underpin the very communities they seek to economically uplift. Thus, the challenges, while daunting, serve as crucibles within which the true feasibility and sustainability of lithium projects are forged, and from which emerges a project paradigm that is not only economically viable but also socially and ecologically conscious.

Despite the encompassing analysis, it is pivotal to acknowledge the limitations of this research. The empirical data availability and the rapidly evolving political and technological landscapes inherently restrict the longitudinal applicability of some findings. The scope of available social and environmental impact data has, in certain contexts, limited the depth to which some aspects could be explored, warranting cautious interpretation of the derived implications.

The findings underline a significant convergence between economic aspirations and sustainable practices. While the tangible and prospective economic benefits are illustrious, the accompanying environmental and social challenges illuminate the imperativeness of balancing economic pursuits with sustainability and ethical imperatives. The lithium projects have, beyond their economic vitality, become symbolic of Portugal's stance towards environmental conservation and social equity, reflecting implications that transcend material and fiscal contours.

The contours of the economic, environmental, and social dimensions explored in this thesis pave the way for future research that can delve deeper into localized impacts and global implications. Research on technological strategies to mitigate environmental impacts, sociological studies on the lived experiences of local communities affected by lithium mining, and explorations into policy mechanisms that can safeguard socio-environmental interests while fostering economic growth emerge as pertinent future research directions.

As Portugal pivots towards a future where economic and sustainable developments are not parallel narratives but intertwined realities, the revelations from lithium exploration projects weave a crucial narrative. The findings of this thesis, entwining opportunities and hurdles, mirror a global paradigm where sustainability and economic growth are perpetually in dialogue, summoning a future where they must coalesce, not collide. This research thereby

does not merely explore a sector but wades through the juxtaposition of growth and responsibility that will ubiquitously define our collective future.

6.1 Recommendations

Given the substantial economic potential and somewhat volatile underpinnings of lithium exploration in Portugal, it is pivotal to establish a framework that not only capitalizes on immediate economic gains but also safeguards against future uncertainties. Thus, there is an imperative to:

1. Engage in continuous market analysis and technology forecasting to stay abreast of global lithium demands and technological shifts.
2. Explore avenues for economic diversification within the lithium value chain, ensuring that the economic benefits are not solely confined to extraction but permeate processing, production, and potentially, recycling of lithium-based products.
3. Cultivate a robust investment climate that attracts sustained domestic and international investments, ensuring that the economic machinery of lithium exploration and production is perpetually energized.

In light of the intricate environmental considerations and challenges that permeate lithium exploration:

1. Implement an integrated environmental management approach, ensuring that ecological considerations are woven into every phase of the project lifecycle, from exploration through to post-production rehabilitation.
2. Explore and invest in technological innovations that minimize ecological impact, thereby ensuring that the environmental cost does not outweigh the economic and industrial gains.
3. Engage in rigorous environmental impact assessments and uphold transparency in communicating these findings to all stakeholders, ensuring that environmental stewardship is embedded within the operational philosophy of lithium projects.

Ensuring that lithium projects are not only economically viable but socially beneficial and acceptable requires:

1. The establishment of robust community engagement frameworks that transcend tokenistic consultations and embed community voices within project planning and implementation.
2. Design and implement a comprehensive social impact management plan, ensuring that the social fabric of communities within which projects are embedded is enhanced rather than eroded.
3. Engage in equitable benefit-sharing mechanisms, ensuring that the economic benefits of lithium exploration are perceptibly experienced within local communities, thereby fostering a symbiotic relationship between projects and communities.

Addressing the regulatory challenges and ensuring that projects are symbiotically integrated within the regulatory landscape necessitates:

1. Continuous dialogue with regulatory bodies, ensuring that projects not only adhere to existing norms but actively contribute to the evolution of regulatory frameworks in light of emerging challenges and opportunities.
2. Ensure that projects are implemented within a framework of legal and ethical integrity, guaranteeing that they not only adhere to regulatory norms but also embody a spirit of ethical and equitable operation.
3. Engage in active knowledge exchange with global counterparts, ensuring that regulatory frameworks and project implementations are reflective of global best practices and innovations within lithium exploration and production.

To ensure that the lithium exploration and production sector is perpetually aligned with emerging trends, technological advancements, and shifting global demands:

1. Invest in continuous research and development within the sector, ensuring that it remains at the forefront of technological, ecological, and social innovations.
2. Engage in international collaborations, facilitating a knowledge exchange that ensures the perpetual infusion of global insights and innovations within Portugal's lithium exploration and production domain.

3. Develop a research consortium involving academia, industry, and governmental bodies to propel the sector forward through informed, innovative, and integrative research and development initiatives.

These recommendations have been formulated to ensure a holistically sustainable, ecologically responsible, socially beneficial, and economically viable future for lithium exploration and production within Portugal, aligning with global demands, technological advancements, and shifting economic, ecological, and social landscapes. Furthermore, they inherently uphold a spirit of transparent, equitable, and integrative operation, ensuring that the myriad of stakeholders, from local communities through to international investors, are collectively navigated towards a future that is not only prosperous but also conscientious and sustainable.

The journey through the multifaceted landscape of lithium exploration in Portugal has unveiled a spectrum of economic, environmental, and social intricacies that navigate between the confluence of opportunity and challenge. This research, while shedding light on tangible benefits and palpable challenges, serves as a conduit for further inquiries, policy refinements, and sustainable practices in the realm of lithium mining and its associated industries. In a world progressively leaning towards electric mobility and sustainable energy solutions, the resonance of this work extends beyond national boundaries, inviting a global dialogue on sustainable practices in mineral exploration and exploitation. May this research not only inform but inspire a future where economic aspirations and sustainability coalesce into a harmonious pathway forward.

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