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影響加拿大鋰業投資的風險因素

Risk Factors affecting Investments in Canadian Lithium

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Abstract

Lithium is one of the most important commodities involved in the global energy transition. Its critical role in the functionality of lithium-ion rechargeable batteries aligns this mineral's supply chain with the market for electric vehicle batteries. By 2040, annual EV sales are expected to exceed 70 million units. Ensuring stable supply chains for batteries is key to EV manufacturing, and building the global supply of battery minerals such as lithium is at the core of this issue. With an estimated 3.26% of global identified lithium supplies, Canada is uniquely positioned to meet the growing demand for this resource. As an emerging market for lithium production, Canada presents opportunities to investors, but also carries notable risks. This landscape is largely shaped by the competitive advantages that Canada holds on the global lithium market, where politically and economically, the nation is aligned with Western interests. Canada's environmental and social contexts also affect lithium projects, whereas technological innovation continues to disrupt this sector. Following a survey of the external landscape factors affecting lithium investments in Canada, a partial risk analysis, summarized into a risk chart to be used by investors, identifies four broad risk areas affecting Canadian lithium: economy, stability, sustainability and technology. Stability and sustainability risk factors exhibit lower risk levels overall, whereas economics and technology reveal the most significant sources of volatility over the course of the coming decades. The results of this research can help inform potential investors in Canadian lithium production.

Keywords. Lithium, Electric Vehicles Batteries, Sustainability, Geopolitics, Technology

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Table of Contents

doi:10.6342/NTU202300492

doi:10.6342/NTU202300492

List of Figures

doi:10.6342/NTU202300492

Chapter 1: Introduction

In recent years, nations across the world have pledged to reach ambitious net-zero carbon emission objectives by the mid-century, promising a momentous shift in energy infrastructure at every level of their economies (Greenpeace, 2020). The widespread adoption of green technology on which this transition depends raises critical questions about the feasibility of national climate plans, the answer to many of which circles back to non-renewable resources. Economies around the world are aiming to phase out their reliance on non-renewable hydrocarbons over the course of the next century, however, this objective is currently only achievable by increasing reliance on a new type of non-renewable resource: minerals.

The anticipated increase in electric vehicle (EV) sales over the coming decades has turned the battery manufacturing sector into a cornerstone of the global energy transition, a sector which is particularly sensitive to mineral commodity markets. One such mineral is lithium. Lithium is used in rechargeable batteries to increase their overall performance and is currently considered the main mineral in the chemical composition of batteries despite ongoing diversification and innovation efforts. The growing strategic importance and required quantities of lithium in the market raise concerns about the stability and sustainability of supply chains.

This thesis will consider the specific case of Canadian lithium supplies in its analysis of the key risk factors affecting investments in this market. Global lithium production is currently far below what is required to meet the anticipated demand, and establishing new supply implies costly and time-consuming steps that increase risk and hinder investment. Furthermore, the vast majority of available global lithium supplies are concentrated in a small

doi:10.6342/NTU202300492

number of geographic markets which exposes supply chains to additional layers of risk. The production of lithium as part of the solution to climate change is often criticised as counterproductive due to its significant environmental and social footprint, and with growing corporate concern over Environmental, Social and Governance (ESG) issues, many research and development (R&D) efforts are seeking to improve extraction processes or even replace lithium altogether as a requirement for energy storage technology. All of these factors contribute to increasing volatility and risk in the future of the global commodity market for lithium.

Canada's current production accounts for less than 1% of the world's lithium output (Natural Resources Canada, 2022). Canadian identified reserves of lithium, however, are the 6th largest, accounting for 2.5% of the global estimated available resource. This nation is in a strategic position to provide a diversified source of lithium to one of the world's largest economies, the United States. Canada's current lithium production is concentrated in the region of Quebec, where various components of EV battery supply chains have been establishing themselves in response to the proximity of critical North American lithium supplies. This includes investments in lithium refining facilities aiming to diversify supply chains away from China, which currently dominates this market globally. Growing levels of investment in Canadian lithium signal a sense of confidence in the potential for this specific market for lithium. The return on these investments will be affected by a number of risk factors, both global and national, as this emerging market for lithium begins to spread its wings. The central research problem that this thesis will seek to address is to identify **what are key risk factors affecting investments in Canadian lithium?**

This research problem will be addressed by building a risk landscape for the Canadian lithium sector. In Chapter 2, an overview of existing literature on the lithium market will be

doi:10.6342/NTU202300492

presented to set the stage upon which risk factors emerge. In Chapter 3, the research methodology will be outlined. In Chapter 4, the main risk areas affecting Canadian lithium projects will be expanded upon, leading into Chapter 5 where these risks will be summarised into a chart to support decision-making.

It is expected that this thesis will produce valuable insight into the risk profile of Canadian lithium projects. The research will aim to deliver a framework for risk assessment to be considered by investors when making capital allocation decisions in the Canadian lithium sector. This framework will provide an overview of the main risk factors affecting lithium production projects and inform strategy development from multiple perspectives.

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Chapter 2: Market Literature

In order to appropriately identify the key risk factors affecting Canadian lithium production, this early chapter will review the existing literature related to this topic. This review will seek to offer an overview of the context in which risk factors would emerge. To do so, the broader context surrounding the EV battery market will be considered as it represents the main driving force behind the push for increased global lithium outputs. Three contextual areas are considered: 1) the global energy transition behind lithium demand changes, 2) lithium extraction sources and the geographic distribution of lithium production and 3) the uses for lithium and the influence that different demand sectors have on the lithium industry.

The problem that the research is seeking to address pertains to stabilizing EV battery supply chains as part of the more extensive EV manufacturing supply chains. EV batteries require extensive mineral inputs and adequate supplies of such minerals are being invested in to meet the expected demand for batteries that will be generated by EV sales. Although many minerals inputs are deemed critical to EV battery manufacturing, lithium is considered one of the, if not the, most important. As research and development efforts continue to optimize the chemical makeup of batteries to increase their overall performance in various aspects, lithium remains the core mineral around which other minerals pivot. Even when considering future generations of batteries currently under development, beyond liquid lithium-ion batteries, lithium remains the most important component. For this reason, lithium is deemed the most relevant mineral to address as part of the proposed research.

doi:10.6342/NTU202300492

2.1. Lithium and the Global Energy Transition

The relevance of lithium supply and its related risk stems from growing importance of this commodity in supplying electric vehicle battery manufacturing, which represents an incredibly dynamic sector due to its role in global energy transition efforts. Lithium is a notable raw material input required for batteries, most famously the lithium-ion rechargeable battery that can be found in most EVs. Lithium-based batteries make EVs run, but they also enable the optimal harnessing of renewable energy and contribute to grid stability in an increasingly electrified society. Sourcing this critical raw material input is one of the earliest stages of battery manufacturing supply chains, where the cost of lithium can have a domino effect as it is processed across supply chains all the way to EV consumers themselves. This binds the destiny of lithium production to that of the world's decarbonization efforts.

2.1.1. Energy Transitions

The global energy transition pertains to the international shift from fossil fuels to renewable sources of energy in both consumption and production that is expected to take place over the course of the coming decades (SP Global, 2020). Growing carbon emissions have been resulting in climate-change led issues around the world which have pushed almost 200 nations to enact policies that will help them meet net-zero emission targets by the year 2050. Emissions resulting from the global energy sector are expected to peak by the year 2030, which is concurrently also the year when electricity produced by renewable sources of energy is expected to exceed electricity produced by fossil fuels. By 2050, it is expected that 85% of the world's power will be generated from renewable sources (McKinsey, 2022). Batteries are critical to managing the energy produced from such sources.

doi:10.6342/NTU202300492

As the international mobilisation to reduce global carbon emission in the coming decades gains momentum, power consumption will also be rising exponentially with energy demand expected to rise threefold by 2050, largely due to the electrification of society (McKinsey, 2022). EVs are one of the many applications that are on track to transform the way society consumes energy. Understanding the volatility of EV demand as a result of policies and consumer behaviours stemming from global energy transitions is key to identifying various risk factors affecting both international and Canadian lithium production as an essential input to EV battery manufacturing.

2.1.2. Electric Vehicles

EV sales have been steadily growing, from 120,000 vehicles sold in 2012 to 6.6 million in 2021 (IEA, 2022). The number of EV models, the variety of available electric vehicles, such as trucks, and the proliferation of charging stations are all contributing to the democratisation of electric personal transportation. In 2021, the Biden Administration approved a USD $7.5-billion funding package to support the development of electric vehicle infrastructure, representing one of many recent legislative actions undertaken by a government committed to accelerating EV adoption (Reuters, 2022).

Estimates forecast the total proportion of electric vehicles on the road in 2030 to be around 20 to 30% (IEA, 2022). By 2040, annual EV sales are expected to exceed 70 million units, with China, India and the United States accounting for more than half of the entire market. Government policies and their associated subsidies as well as macroeconomic factors are currently significant elements shaping EV market dynamics across different global markets.

doi:10.6342/NTU202300492

In China, half of total 2021 global EV unit sales were recorded in the country and a growing variety of models at lower price points are expected to push unit sales to over 15 million annually by 2030 (Somwanshi, 2022), even as financial incentive programs being dropped in some markets. In the United States, electric vehicles are expected to account for 52% of the total vehicles sold annually, a reality which is largely being driven by the current financial incentives established by the Biden Administration (Boudway, 2022). The high price of oil driven up by supply disruptions and sanctions following Russia's invasion of Ukraine have also made the switch to EVs more attractive for many consumers (IEA, 2022).

Economies of scale generated from increased production to meet this growing demand will contribute to lowering EV prices worldwide over time, but price volatility is also expected to keep prices up due to the rising costs of the raw materials required in EV production, many of which are very different from those required in the manufacturing of fossil fuel vehicles. In 2022, the average cost of raw materials required to produce an EV is US$8,255, up 140% since 2020 (Wallace, 2022).

The cost of batteries represents one of the most significant cost drivers for EVs, and fluctuations in the price of raw materials used in battery manufacturing, such as lithium, nickel and cobalt, are the reason for this. On one hand, technological advancements in improving battery performance have been increasing the overall quantity of raw materials used in battery production, which accounted for 50-70% of battery costs in 2022, up from 40-50% in 2017 (IEA, 2022).

Further compounding this required quantity increase, supply chain disruptions and scarcity concerns have also contributed to raising the price of these commodities. In 2021, lithium and cobalt commodity prices doubled, and in 2022 lithium prices have surged 2.5 times (Kim, 2022). This rise can be explained by a number of factors including recent supply

doi:10.6342/NTU202300492

chain disruptions and concerns regarding the available quantity of these minerals (IEA, 2022). In fact, many observers point to shortages of such raw materials as one of the main risk factors in slowing global EV adoption and the wider adoption of other clean energy technologies, and in turn threatening the world's decarbonization targets (IEA, 2022). Investments in improving battery technology to mitigate the chemical volatility of lithium and investments in supply chains will help stabilise EV prices over time, but until this battery supply chain issue is resolved, the EV market will be subject to unpredictable volatility.

An important difference to note is that in this case, the volatility pertains specifically to the price of manufacturing EVs themselves, as opposed to changes in the price of oil which mainly affect a vehicle's cost of operation. It could take decades before lithium output levels are sufficient for the expected EV demand to be met (IEA, 2022).

Batteries represent a core component of any EV's performance. Through its position in battery manufacturing supply chains, the lithium market's unmistakable reactivity to the EV automotive industry will be a key risk area to be monitored by lithium investors. EVs have been the subject of enhanced attention and public awareness in recent years. The notion that EVs may be experiencing inflated hype is a concern that battery manufacturers and lithium producers have when considering how this may indeed affect demand in their respective interrelated industries. The insufficient speed at which EV infrastructure such as charging stations is being developed is one factor that has the potential to slow the EV adoption momentum. External factors affecting battery mineral commodity prices are also ironically another factor that injects vulnerability into the economics of EVs, threatening to make EVs more expensive and less attractive to consumers than the current enthusiasm would suggest. Overall, it would appear that despite these factors, both vehicle manufacturers and consumers are committed to the shift to battery vehicles.

doi:10.6342/NTU202300492

2.2. Lithium Market Background

Lithium is an alkali metal characterised by its white colour, its soft texture and its shiny appearance. It is the lightest of the solid elements of the periodic table of chemical elements and is a highly reactive and flammable substance. Lithium is highly corrosive, ignites upon contact with water and can cause severe damage when coming into contact with human skin. Its chemical volatility is in fact the most notable drawback of using lithium in batteries and represents the most significant pain point that research and development efforts are attempting to innovate out of the current generation of liquid lithium-ion batteries.

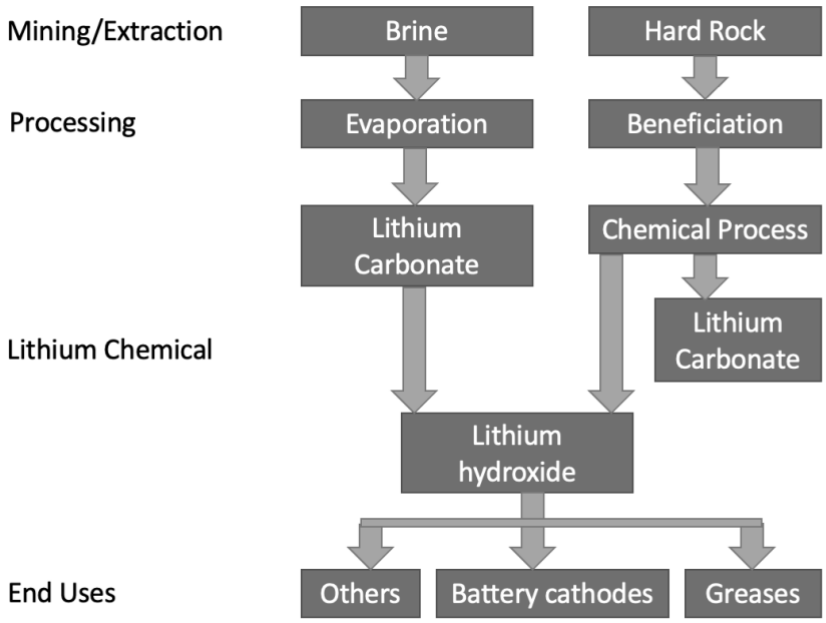
Lithium can be found in mineral ores, as well as in brine deposits and mineral spring salts (Dye, 2022). Most of the risk factors affecting lithium production are inherently tied to the very nature of this mineral and its presence in the environment. In fact, the entire lithium market is largely shaped by the types and geographic location of available sources for lithium extraction.

2.2.1. Extraction Sources

The lithium sector refers to a variety of both extraction and processing activities. There are currently two commercially scalable sources for extracting lithium in the market: brine and spodumene ore, also known as “hard rock”. Both of these sources are very different in nature, are found in completely different environments and involve fully distinct supply chains and processing activities to produce similar finished products. The nature of lithium extraction is an important driver of risk in this sector as it establishes the global capacity for supply of this mineral. Traditional extraction sources present diverging cost structures, supply chains and market advantages, whereas new sources being researched have the potential to completely disrupt and flood the market for this valuable resource.

doi:10.6342/NTU202300492

Figure 1: Lithium Supply Chains



Note. Adapted from: International Energy Agency. (2022). The role of critical minerals in global energy transitions, https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions/ (Accessed 2022-09-20)

Lithium Brine

Lithium brine is the most common resource from which lithium is extracted for commercial purposes. It can be found in arid regions of the world where saline groundwater has either naturally or artificially formed into surface ponds and salt flats, and where fast evaporation has been known to leave behind highly concentrated lithium mineral deposits in a limited number of locations around the world. Most of the active lithium brine extraction operations are being carried out in desert regions of Northern South America and Western China.

doi:10.6342/NTU202300492

The main output of brine-based extraction activities is lithium chloride, which is the main element used in lithium-ion rechargeable batteries. Following hundreds of days of evaporation and after chemically removing other elements, the ponds leave behind lithium chloride which is directly extracted and marketed to end users (IEA, 2022). Lithium chloride extracted from brine can also undergo additional processing to be transformed into a different by-product, lithium hydroxide, which makes more sustainable and longer lasting batteries (Bisley International, 2021).

The advantages of lithium brine operations are that resource prospecting is easier, establishing production is quicker and typically capital requirements are lower when compared to hard rock operations (Desjardins, 2015). Furthermore, emerging technology for direct lithium extraction, which would skip time-consuming evaporation process, promises to significantly reduce cost and lead times by removing lithium carbonate directly from non-concentrated brine (IEA.org).

Lithium Hard Rock

Lithium extracted from hard rock involves more straightforward mining operations. It is found in spodumene ore where it is mixed with aluminium. Spodumene ore can be found in a broader spectrum of geographic locations when compared to lithium brine, but prospecting for this resource is also more time-consuming and costly. However, once a spodumene resource has been identified, streamlined operations enable faster and more efficient extraction of deposits over time (Desjardins, 2015).

Currently, the majority of hard rock lithium is extracted in Australia. The biggest difference between lithium brine and lithium hard rock is that finished products cannot be extracted directly from hard rock. Spodumene ore needs to undergo a secondary transformation process following its extraction where it is chemically transformed into either lithium chloride or lithium hydroxide.

doi:10.6342/NTU202300492

As exhibited in Figure 1, lithium supply chains involve additional refining when sourced from hard rock. The majority of refining activities currently takes place in China, which currently supplies close to 60% of refined lithium carbonate and hydroxide globally (IEA.org). In fact, China imports most of the mined lithium from Australia and refines it for use in the battery industry. Due to the increasing appeal of lithium hydroxide in battery manufacturing and the lower cost of producing it from hard rock compared to brine, lithium ore exports to China are expected to increase significantly in the coming years.

Since the process of generating lithium hydroxide from hard rock is more straightforward than it is to do so from lithium brine, hard rock lithium is considered a more flexible resource which is also faster to process once production has been established. Furthermore, lithium ore also typically produces higher quality lithium products (Piedmont Lithium, 2022).

Alternative Sources

New sources for lithium extraction are also being explored, the most advanced being mineral clay. Lithium clay-based operations are attracting investments in the southwestern United States, with the promise of lower processing and less costly lithium extraction. However, the lower quality of the end product has so far made this source of lithium difficult to scale for commercial uses (IEA, 2022).

Extracting lithium from other unrelated industrial processes also appears to be a viable source of supply for the market. Lithium extraction from waste rocks from the production of a different mineral compound, borate, is actively being looked into as a viable supply for lithium products. Extracting lithium from brine being pumped at geothermal power plants is another source which has been garnering a lot of interest in the industry, in part because it bypasses the

doi:10.6342/NTU202300492

need for evaporation ponds and reduces the environmental footprint of lithium brine extraction activities (Domonoske, 2022).

Recycling lithium from existing batteries is another promising source being considered for the long term supply of the market, and large lithium firms like Albemarle are investing in expanding this specific capacity. However, recycling lithium will only become a more sustainable source at a time when sufficient quantities of batteries will have already been produced in the first place (Domonoske, 2022).

New alternative sources of lithium extraction, including the circular economy implications of recycling lithium altogether, hold the potential to significantly disrupt the current lithium sector status quo, representing a notable risk and a potential source of volatility for this growing market. Expanded capacity for supply in the market would however have a transformational and likely positive effect on the client industries for lithium as well as for environmental sustainability.

2.2.2. Lithium Production Markets

The world's lithium producing markets can be divided into two groups: actual lithium production and the potential for lithium production. The current output of lithium is far below the potential for output when considering the world's identified but undeveloped lithium resources. What's more is that every year, new sources are being identified. Canada is one of the markets which is estimated to hold the potential for significant lithium output, even though current production is minor on the world stage, though scaling Canada's lithium output will require significant investment levels in the coming years. The layout of both global identified and in-production supplies is key to the strategic orientation of Canada's lithium sector.

doi:10.6342/NTU202300492

Identified Reserves

The breakdown of lithium reserves around the world, from both brine and hard rock sources, are presented in Figure 2. They represent the total quantities of identified lithium held by each nation regardless of whether this resource is actually being exploited for production, and it is important to underline that these numbers have been increasing every year as investments in exploration, leading to the identification of new lithium resources worldwide, have been increasing in recent years (USGS, 2022).

The Atacama desert region of South America, often referred to as the "lithium triangle", is shared between Bolivia, Chile and Argentina and is by far the world's most lithium-rich region with over 45% of the world's identified lithium reserves concentrated in local brine. The United States also holds significant reserves of lithium brine. Australia holds the world's largest hard rock reserves accounting for over 8% of total identified reserves.

Figure 2: World reserves of lithium by country (USGS, 2022)

Ranking	Country	Lithium Content (tonnes)	Percentage of the total
1	Bolivia	21,000,000	23.60%
2	Argentina	19,000,000	21.35%
3	Chile	9,800,000	11.01%
4	United States	9,100,000	10.22%
5	Australia	7,300,000	8.20%
6	China	5,100,000	5.73%
7	Congo	3,000,000	3.37%
8	Canada	2,900,000	3.26%
9	Germany	2,700,000	3.03%
10	Mexico	1,700,000	1.91%
11	Czechia	1,300,000	1.46%
12	Serbia	1,200,000	1.35%
13	Russia	1,000,000	1.12%

doi:10.6342/NTU202300492

	Other	3,900,000	4.38%
	Total	**89,000,000**	**100.00%**

Note. Adapted from : U.S. Geological Survey. (2022). Mineral commodities summary 2022 - lithium. https://pubs.usgs.gov/periodicals/mcs2022/mcs2022-lithium.pdf (Accessed 2022-11-10)

Active Producers

The geographic location of active lithium production also has an impact on future supply. With extensive exploration and capital expenditures already being carried out, regions with ongoing production have already established supply chains with the potential to streamline and simplify new extraction and processing projects. As a result, expanding the capacity of existing supply chains will attract investment, lower start-up and operating expenses and reduce lead times when compared to establishing new production in underdeveloped locations. Figure 3 presents the nations which currently produce the largest lithium outputs. It is important to note that information on production volumes generated within the United States is unavailable as it would disclose private company proprietary data, though this market represents one of the world's largest.

Figure 3: World reserves of lithium by country (USGS, 2021)

Ranking	Country	Production (tonnes)	Percentage of the total
1	Australia	55,000	63.95%
2	Chile	26,000	30.23%
3	China	14,000	16.28%
4	Argentina	6,200	7.21%
5	Brazil	1,500	1.74%
6	Zimbabwe	900	1.05%
	World	**86,000**	**100.00%**

Note. Adapted from : U.S. Geological Survey. (2022). Mineral commodities summary 2022 - lithium. https://pubs.usgs.gov/periodicals/mcs2022/mcs2022-lithium.pdf (Accessed 2022-11-10)

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Canadian Supply

In terms of supply, Canada is a small yet ambitious player in the global lithium market. The second largest country in the world by land mass only holds 3.26% of global identified supplies of lithium, approximately 2,900,000 tonnes of the mineral, but this supply is also uniquely positioned in offering a number of competitive advantages to key markets, and its capacity is quickly expanding.

Canada's identified reserves of lithium can be found in both hard rock and brine sources. These identified reserves currently exclude the potential for alternative sources of extraction for which commercial scalability has not yet been proven. The most developed lithium production in Canada is located on the Canadian Shield, south of James Bay nestled between the provinces of Quebec and Ontario. The Canadian Shield is a vast ancient geological area spanning 8,000,000 km^2 from the North American Arctic to the Great Lakes region at the interior of the continent. In the western Prairies of Canada to the East of the Rocky Mountains, where the terrain is flat and the climate is dry, lithium brine resources have also been identified and are being explored.

Considering the size of Canada's territory, much of it remains virtually unexplored, especially in its northern reaches. Some experts estimate that the country may hold many more undiscovered lithium deposits. The northern part of the Canadian Shield, shared between the territories of Nunavut and the Northwest Territories already host extensive mining operations for various other resources, but much of the area remains unexplored, which has been fuelling lithium prospecting interests (Government of the Northwest Territories).

doi:10.6342/NTU202300492

Figure 4: Canadian Lithium Projects (2021)

Note. Sourced from Natural Resources Canada. (2022). Lithium Facts. https://www.nrcan.gc.ca/our-natural-resources/minerals-mining/minerals-metals-facts/lithium-facts/24009/

Canada's actual lithium output is currently very small and volatile compared to the amount of reserves it holds. Canada is actually a net importer of lithium with imports worth CAD 161 million in 2020 and CAD 139 million in 2019 from four main markets: China, Chile, Russia and the United States (Natural Resources Canada, 2022). By contrast, in 2020, Canadian lithium firms only exported CAD 12.8 million worth of lithium, for 86 tonnes, to China and France. This represented a significant decline from the 41,000 tonnes in 2019 and the 97,000 tonnes in 2018 that Canada exported. The main reason for this decline was dwindling prices that pushed two lithium mines in the Abitibi-Temiscamingue region of northern Quebec to cease their operations (Natural Resources Canada, 2022). Since 2020, both mines have begun to resume production as

doi:10.6342/NTU202300492

the steep increase in lithium prices makes its supply more economically viable. After seeking bankruptcy protection in 2019, the Whabuchi mine (Nemaska Lithium) and North American Lithium mine (Sayona Quebec) were both acquired by different national and international interests who are now taking Quebec's lithium supply into a new strategic direction by investing in local refining operations for the hard rock lithium resources produced by the mines.

2.3. Lithium Market Forces

Demand for lithium has been growing in recent years in large part due to the proliferation of renewable energy solutions and applications, most notably EV batteries. Lithium's main function in such applications is to enable rechargeable lithium-ion batteries, which present high levels of energy density when compared to competing battery types by enabling the continuous flow of lithium ions while the battery is being drained or recharged (Department of Energy, 2022). Such batteries are used in laptops and smartphones, but are also critical in ensuring electrical grid stability and for enabling the use of EVs. Lithium-ion battery manufacturing accounted for 71% of lithium demand in 2020 (Natural Resources Canada, 2022), and in 2030, it is expected to account for 95% of lithium demand (Azevedo et al., 2022). As a result, the forecasts related to this specific use for lithium production are what are driving new investments in this sector.

2.3.1. Lithium Demand

Extracted lithium compounds are most commonly processed for commercial use as lithium carbonate, lithium oxide and lithium hydroxide. In these forms, lithium is used in a variety of activity sectors, and most notably in batteries, as well as in different glass, ceramics, lubrication products and even in some medication (Natural Resources Canada, 2022). The most prominent end use for lithium is in lithium-ion batteries, which are widely used in many industries such as

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the automotive and consumer electronics industries. Lithium's essential role in the performance of batteries used in EVs has contributed to increasing the value of this mineral in recent years.

While the world's volume of lithium supplies fluctuate as exploration activities lead to the discovery of new resources and new production projects break ground, demand forecasts for lithium products present an even more volatile picture. In fact, considering identified lithium supplies, the question of how much lithium production capacity is optimal to meet demand is increasingly critical in swaying investment decisions. Too much production will flood the market, affecting prices and economic viability whereas too little may lead to a shortage of lithium, raising prices and making end user products such as EVs more expensive and harder to sell. This underscores the importance of successful lithium demand forecasting models. The variability of lithium demand forecasts is so great that the market cannot currently predict whether there will be a shortage or a surplus of lithium in the coming decades.

Demand Forecasts

Current lithium demand forecasts are based on scenarios that exhibit many moving pieces. Common to most forecasts is the notion that battery manufacturing, specifically for EVs, will be driving up lithium demand dramatically over the course of the coming decades as societies around the world adopt this new and arguably more sustainable mode of transportation. However, the quantity of EVs sold, the speed of adoption and advancements in battery technology all make it difficult to accurately predict the demand of lithium. Furthermore, politics is equally if not more accountable for the uncertainty of future demand in lithium.

Governments around the world have implemented ambitious decarbonization objectives that are supported by massive renewable energy infrastructure investments and financial incentive programs designed to encourage consumers to purchase EVs. While these programs are supporting

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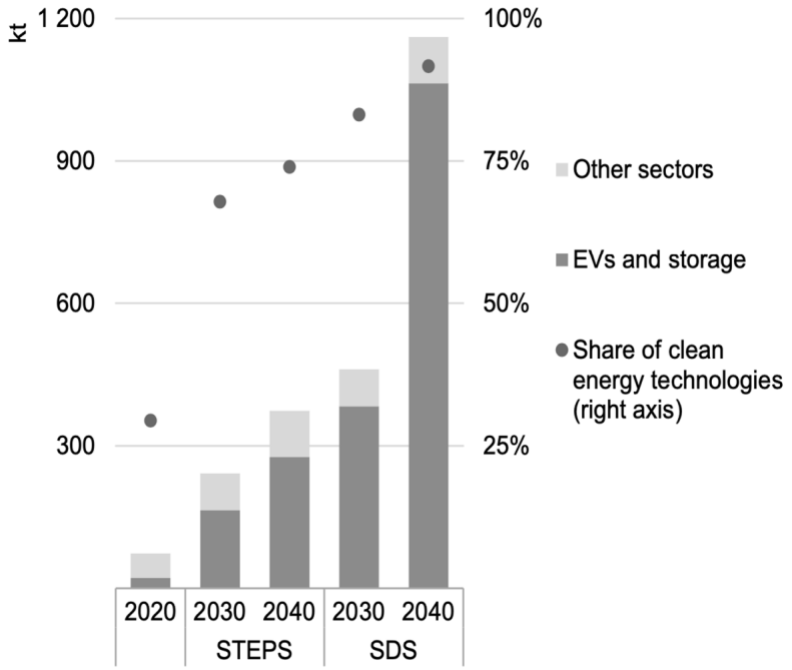
greater EV sales in the present, they are not intended for the long term and as a result they are having a direct influence on the quantity of EVs sold and the speed at which they are sold. Naturally, because lithium is critical input in battery manufacturing, these considerations also have a direct impact on lithium demand. The vast majority of lithium carbonate and lithium hydroxide demand is expected to be generated by the EV industry as exhibited in Figure 5, and this specific demand should increase over time regardless of the observed scenario.

Figure 5: Total Lithium Demand by Sector and Scenario



Note. Sourced from: International Energy Agency. (2022). The role of critical minerals in global energy transitions, https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions/ (Accessed 2022-09-20)

In the lithium demand forecasts studied by the International Energy Agency, two specific scenarios are studied: STEPS and SDS (IEA, 2022), as presented in Figure 4. STEPS represents the Stated Policies Scenario, which considers current international policies and plans surrounding climate change and where they are expected to lead lithium demand. SDS is the

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Sustainable Development Scenario which assumes that international climate change targets as set by the Paris Agreement are fully met. SDS is therefore more of an optimistic scenario whereas STEPS is a rather realistic scenario considering active measures in place.

Beyond the IEA, leading forecasters also make wildly different projections for lithium demand, especially in the short term. On the lower end, lithium supply deficits as large as 13% of the total demand are anticipated, while on the upper end, a surplus of up to 17% of the total demand is expected (Burton, 2022). Market size projections also vary greatly, with analysts estimating annual sales will range from 502,000 tonnes to 1,300,000 tonnes on an annual basis. In each of the considered forecast scenarios, however, growth levels are very optimistic, all of them forecasting over 20% annual growth until 2025. For perspective, Chile's SQM, one of the world's leading lithium suppliers, observed an annual demand increase of 50% in 2021. These growth levels clearly demonstrate that the lithium industry is undergoing fast-paced expansion, especially when compared to more mature mineral industries like copper, which are accustomed to 2 to 4% annual growth levels (Burton, 2022).

2.3.2. Technology Sector

Technological innovation in the battery industry could also have an unpredictable effect on lithium demand. Currently, the battery industry has maintained lithium at the centre of its research and development efforts, focusing on battery optimizations that revolve around this mineral. Liquid-based lithium-ion batteries already enable more sustainable and better performance batteries, and it is expected that the next generation of lithium-based batteries, all solid-state batteries (ASSBs) will perform ever better with a superior energy density than their liquid-based predecessor. ASSBs will also greatly reduce the chemical volatility of lithium, making them safer to use in a wider array of products.

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Furthermore, the battery industry knows it can rely on the supply of mining-friendly and investment-friendly lithium suppliers such as Chile and Australia, which lowers the overall risk associated with this resource. As a result, even if different mineral mixes are being researched in the hopes of finding new energy storage technology breakthroughs, the demand for lithium is expected to remain consistent for the foreseeable future as the world transitions to EVs and renewable energy applications.

Long term lithium demand forecasts beyond 2030 will largely depend on the evolution of government policies and investments relevant to EV adoption as well as on macroeconomic conditions. Furthermore, new technological innovations in energy storage solutions may either require larger quantities of lithium or create the need to find substitutes to the mineral, both of which could also have a transformative impact on lithium demand. Uncertainty in forecasts and the absence of predictable data can also result in price fluctuations when suppliers feel vulnerable, which in turn also has an effect on demand. Supply chain transparency has an important role to play in this sense. This all paints a reality that the lithium sector will need to grapple with until it begins to mature.

Technology Sector and ESG

Lithium production and the demand that drives it is intimately linked to the growing importance of sustainable sourcing policies and processes being implemented in key industries that use lithium as a raw material. Though EV batteries represent the most significant anticipated driver of lithium demand, in reality every industry relying on batteries will also hold sway over the future of lithium demand, including consumer electronics and renewable energy technology manufacturers.

doi:10.6342/NTU202300492

One notable instance of the influence that other sectors might have on lithium production is Apple, as one of the leading manufacturers of smartphones in the world. The tech giant's commitment to carbon neutrality has had a profound impact on the way it sources its raw material inputs (Apple, 2022). It is but one example of many companies implementing similar ESG policies that have an impact on its downstream suppliers.

Apple has implemented policies to create more circular economy opportunities in its sourcing. Given that lithium used in rechargeable batteries represents a key input of many of Apple's products, battery recycling to retrieve lithium resources could influence the way current lithium and battery supply chains are shaped. Furthermore, another of Apple's sustainability policies includes "Smarter Chemistry" in its products and processes. One example of this is the chemistry used in batteries to optimise performance, which directly impacts the quantity of lithium used in manufacturing.

Apple has also made commitments to sourcing raw materials from suppliers that are socially and environmentally sustainable. This consideration for ESG in its procurement strategy will directly impact lithium suppliers and the markets in which they operate. Lithium producing markets placing a greater emphasis on environmental regulation and healthy stakeholder relations will hold a competitive advantage in this context.

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Chapter 3: Methodology

Following the background provided on the lithium market and its potential risks based on a review of the existing literature on this topic, a further risk assessment exercise was carried out in order to build a risk chart to be used by potential investors in identifying risks in the Canadian lithium sector. This directly supported the central research problem for this thesis which is to identify the key risk factors affecting investments in Canadian lithium.

A risk analysis methodology was employed to conduct this research. A partial market risk analysis was carried out as part of this thesis, focusing on the identification of risks. This analysis was supported by data collection from secondary sources using a thematic analysis approach as well as from an interview. Results from the conducted risk analysis are summarised into a risk chart whereby risks can be easily considered and scored by potential investors.

3.1. Market Risk Analysis

A market risk analysis is conducted to observe and identify sources of uncertainty and volatility pertaining to expected and forecasted results of business operations and strategies. Traditionally, a market risk analysis features three steps (Vector Solutions, 2019):

1. Identification of risk factors
2. Estimation of the risk level
3. Development of mitigation strategies

Using this approach can support decision-making by delivering a framework to prioritise risks based on their impact on business operations and results, and by informing strategy development in order to reduce volatility and incorporate risk mitigation tactics. This framework was selected in the context of the current research because it represents a pragmatic approach to

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turning data on risk into useful information for strategy development and decision-making, which is the ultimate aim of this research.

Market risk incorporates a broad array of potential sources of uncertainty. In the context of this thesis, the analysis focuses on external environment risk factors by conducting a thematic analysis of secondary data sources using a PESTEL (Political, Economic, Social, Technological, Environmental, Legal) approach to support the risk identification exercise.

3.1.1. Data Collection

Data from secondary sources informed the chosen risk analysis methodology. These sources include industry reports, government policies and new articles selected using a thematic analysis approach.

A thematic analysis of data involves establishing thematic patterns throughout literature on a specific topic and "coding" these patterns, such as observed trends, attributes or issues pertaining to the topic, into identifying further sources of data (Chawla, Wood, 2021). As such, in the initial familiarization stage of a thematic analysis, major ideas emerging from broad lithium industry reports are isolated in identifying further sources of data on these specific ideas. As part of this familiarization process, industry reports from the International Energy Agency were particularly instrumental in providing key data to inform the thematic analysis. The main report that was consulted, entitled "The role of critical minerals in global energy transitions" provided significant insight into key topics related to the research problem, including data on the EV industry, batteries and lithium markets facts. A number of government publications were also consulted during the familiarization process. The U.S. Geological Survey's "Lithium Mineral Commodity Summary 2022" was particularly useful in qualifying global lithium supplies and key industry challenges. Natural Resources Canada's "Lithium Facts" web publication was also a key source of data for

doi:10.6342/NTU202300492

the general lithium market. This “rabbit-hole” approach leading to more comprehensive areas of research is useful for narrowing in on key issues that help advance the research.

The thematic analysis was additionally carried out under the broad umbrella of a PESTEL structure in order to comprehensively capture the external landscape of Canada’s lithium sector. A PESTEL framework is used to study external factors that affect operations and business results. It includes consideration of six key risk areas including political, economic, social, technological, environmental and legal contextual areas. For each of these risk areas, the full landscape of factors and trends related to lithium production globally and in Canada presented somewhat of a garden from which key risks will be harvested.

Additionally, an unstructured interview was conducted with a professional working in Canadian mine financing to substantiate the results of the first layer of research and to gain additional on-the-ground insight on the research problem.

3.1.2. Details on the interview

Name: Xavier Chagnon, P.Eng.

Current role:

- Business Analyst - Corporate Development and Capital Markets at Quebec Iron Ore Inc.
- President at Young Mining Professionals Montreal

Background:

Before moving to the iron sector, Xavier worked as a mining engineer at Nemaska Lithium. This company owns a Quebec-based mine which is one of the most significant lithium projects in Canada. Xavier was employed by Nemaska as the mine shut down in 2019 due to dwindling lithium prices, was involved in bankruptcy protection procedures and left the company as it was

doi:10.6342/NTU202300492

in the midst of an acquisition with the intention of resuming production. He has extensive knowledge of the Canadian lithium and mining sector in general, and has a good knowledge of industry trends and mining capital markets.

Topics and questions covered during the interview:

- Importance of ESG issues in current mining operational and financial decision-making, namely the weight of good stakeholder relationship management with local Indigenous communities. .
- Current prospects of Canadian lithium production, including the development and potential for alternative extraction sources.
- Confidence levels of investors in the Canadian mining sector and the state of the capital markets for mining projects.
- Background on Quebec-based lithium mining operations in Abitibi-Temiscamingue region.
- North American lithium-ion battery supply chain developments.
- Anticipated success rate of current lithium mining interests in the Canadian sector.

3.1.3. Risk Chart

At the conclusion of the risk analysis methodology pertaining to risk factors affecting the Canadian lithium sector, identified risks were represented into a risk chart to be used by investors to inform capital allocation decision-making. This chart is divided into the key risk groups that are subdivided into a series of more specific risks.

Following the thematic analysis of data, four overarching forces emerged as having strategic importance in the dynamics of the lithium market, and by extension the risks that affect it. As a result, the literature review identifies four broad risk groups that are the target of the research and form the basis for the risk chart to be designed in conclusion. These four groups are:

doi:10.6342/NTU202300492

1) Stability, 2) Economics, 3) Sustainability and 4) Technology. These groups also happen to loosely align with the PESTEL approach to analyse the external landscape of the lithium market.

The research targeting the four risk groups more specifically considers the following questions:

1. Stability: the geopolitics of lithium and how supply chains for this critical mineral are made more vulnerable by the diverging interests of global actors; the intervention of governments in domestic lithium markets; the stability and accessibility of capital markets; the transparency of lithium supply chains and their regulatory context.
2. Economics: the impact of lithium commodity price fluctuations on supply; the variability of demand; the identified and estimated global supplies of lithium; the impact of macroeconomic factors on the lithium market.
3. Sustainability: the environmental impact of lithium production; the frequency and nature of lithium-related accidents affecting natural environments and neighbouring communities; the environmental regulation affecting lithium production; the impact of lithium production on local communities and other stakeholders; the costs of lithium-related ESG policies.
4. Technology: the potential for change that innovation in lithium production represents; the alternate sources of lithium extraction under investigation; the technology products that require lithium as an input and the disruption they may cause to lithium demand; the potential for lithium recycling as a viable replacement to lithium extraction.

doi:10.6342/NTU202300492

The risk chart provides an easy to use table of external risk factors to consider, monitor and investigate further if a specific risk area is deemed especially critical in the context of a given investment project.

The risk chart lists the four risk groups and their respective risk subtypes, with each risk scored according to their scope and their level of impact.

Scope is measured as either regional, national or global. A regional impact is exercised by a risk that affects local community stakeholders and their environment, whereas a national impact is related to a risk that has the potential to disrupt only national supply chains for lithium or on the other hand that pertains to the specific circumstances of a lithium-producing nation. A global impact pertains to risks that have the potential to disrupt global lithium supply chains as they currently exist.

The impact level is divided into five qualitative categories to which scores are associated: low (1), low-moderate (2), moderate (3), moderate-high (4) and high (5). These impact levels are a function of the likelihood of their occurrence and the degree of disruption they have the potential to generate, with the degree of disruption holding precedence over the likelihood of occurrence. For example, a low likelihood of occurrence and a low degree of disruption leads to a score of "low" or 1. A high likelihood of occurrence with a high degree of disruption leads to a score of "high" or 5. A high likelihood of occurrence paired with a low degree of disruption leads to score of "low-moderate" or 2, whereas a low degree of occurrence paired with a high degree of disruption may lead to a score of "moderate-high" or 4. A nuanced balance between both factors leads to a score of "moderate" or 3.

The scoring system aligns with the literature's presentation of the external landscape of the lithium market. Regarding scope, the literature repeatedly establishes risks as exercising clear

doi:10.6342/NTU202300492

levels of geographical impact as defined in this section. The scope of individuals risks therefore clearly appear in the risk chart's summary. Impact levels, on the other hand, are the most consequential measurement from an investor's perspective and represent the ultimate output of the proposed research. Establishing the impact of an identified risk and presenting it in a straightforward way is the objective of the proposed scoring system.

Scope and scores are to be attributed to individual risks in the risk chart based on the findings from the conducted research. The collected data from secondary sources and from the interview have been leveraged to generate the proposed scope and score of risks. It is therefore important to note that scope and score represent subjective measurements generated by the interpretation of the research results.

doi:10.6342/NTU202300492

Chapter 4: External Risk Factors

Lithium represents a fast-growing incredibly dynamic activity sector the scale of which is actively being swayed by a variety of competing forces. One on hand, supply is determined by the nature of the source from which lithium is extracted, by the geopolitics and the physical geography affecting supplying nations as well as by ESG considerations and the volatility of lithium prices that affect new production developments. On the other hand, demand is being driven by global EV adoption and the associated government policies and incentive programs that support it. Lithium demand is also a function of evolving energy storage technologies and their respective lithium requirements. In the following section, these market dynamics will be considered in the specific context of Canadian lithium production.

This chapter unfolds the risk analysis methodology that was selected to address the research problem. Based on the market literature for the Canadian lithium sector and inspired by the PESTEL framework, the risk analysis outlines for broad risk areas as part of the research: stability, economics, sustainability and technology.

4.1. Stability Factors

One of the most consequential angles with which lithium supply chains have been observed is through the lens of geopolitics. Given the importance of this mineral in a number of strategic industries, nations occupying positions within this supply chain may use them as leverage to exert influence over world affairs similarly to the way that oil-rich nations historically have. The geopolitics of lithium supply chains have therefore been powerful in shaping national narratives, strategies and investment levels in this mining sector in particular. Observing the international context for lithium production and how it affects the potential for success of Canadian firms in this commodity market will generate stability risk factors relevant to investment decisions.

doi:10.6342/NTU202300492

4.1.1. National Security Concerns

Due to its importance in strategic economic sectors, lithium is part of a large family of minerals often referred to as “critical minerals”. Minerals deemed critical vary from one nation to the next, and strategies to address the vulnerabilities they create also vary in scope depending on the nation and its respective economic sectors of importance. All critical minerals, however, play a role in ensuring a successful renewable energy transition. In the United States, the evolving list of critical minerals now includes 50 metal and nonmetal commodities which are considered to play “a significant role in its national security, economy, renewable energy development and infrastructure” (Burton, 2022).

Given the importance of lithium in the global energy transition as well as for its use in other industries, the stability and predictability of supply is itself key to social, economic and environmental stability. Political instability within lithium-rich nations makes global supply chains vulnerable and hinders investment in developing new resources. Bolivia’s Salar de Uyuni is the world’s largest and virtually unexploited reserve of lithium brine in the world, yet its development is hindered by the lack of a legal framework on lithium activity, the lack of political consensus surrounding fiscal issues, as well as public opposition to development projects (Rochabrun, 2022).

Therefore, political stability of supply is one of the key risk factors affecting the global lithium market, and this perception of stability is innately tied to the much broader enduring power dichotomy that is shared between the East and the West. China’s dominating position in the world supply of refined lithium is perceived as a national security threat to many western-aligned nations, who would rather rely on more diversified sources of critical minerals originating from markets with similar legal and regulatory contexts as their own. Many industries and nations view China’s leverage on the refined lithium market as making supply chains vulnerable to geopolitical

doi:10.6342/NTU202300492

disagreements and localised price fluctuations, similarly to the impact that Russia's invasion of Ukraine and the ensuing sanctions had on oil and gas supply in Europe. As a result, new lithium investments are aiming to diversify and expanding global lithium supplies.

As one of the world's largest markets, the United States is particularly vulnerable to China's supply of critical minerals considering the global context, and it has been actively engaged in securing more stable and more "friendly" supply to meet its growing demand for EV batteries and other technologies (Reuters, 2022). From this perspective, Canada is a politically stable, low risk and "friendly" nation with significant lithium resources that is right on the doorstep of one of the largest markets for lithium in the world.

From this perspective, politics will play a significant role in supporting the North American lithium market. The American government will seek to invest in expanding and stabilizing lithium supply chains, and this primarily affects North American lithium production, as well as production within allied nations. This is supported by the fact that lithium is considered critical to national security interests in North America, and also due to the major role that automotive manufacturing plays in the North American economy. Canadian politics are also in line with supporting the national lithium sector as it presents economic opportunities, but also political ones.

4.1.2. Positioning Canadian Lithium

Canada has recently entered into a partnership with the United States and other nations to establish secure supplies of critical minerals to counter China's domination in several battery mineral markets by driving new levels of public and private investment into supply chains (Reuters, 2022). All of the current and anticipated supplies of United States-sourced lithium are insufficient to meet the expected battery demand associated with EV battery demand (Ewing, 2022). The United States is increasingly turning to Canadian lithium supplies to complement its own, and

doi:10.6342/NTU202300492

refined lithium supplies bypassing China will give Canada an advantage in supplying the giant EV battery market to its South.

Canadian lithium firms have been actively investing in establishing low risk and high-quality sources of lithium to supply the fast-growing battery manufacturing needs of the United States which in turn is seeking to diversify its suppliers, obtain lithium at a lower cost and stabilise supply chains. Canada has strategically been aligning its lithium production with the sizable market that its largest trading partner represents.

Quebec's main market for exporting lithium hard rock, just as is the case for Australia's dominant supply, is China, which refines most of the world's hard rock into either lithium carbonate or lithium hydroxide. In this context, Quebec's only viable strategy is to engage in a price war to compete with Australia, a nation which has the benefit of proximity with China and better access to capital (Bourrassa). Quebec lithium interests are now actively investing in establishing local lithium hydroxide refineries to transform lithium hard rock locally rather than export it. Demand for lithium hydroxide is expected to grow significantly in coming years as it contributes to producing better performing batteries. Nemaska Lithium President & CEO Guy Bourrassa has stated that this strategic move will enable it to capture 10% of the world's lithium carbonate demand and up to 45% of the lithium hydroxide demand in the next five years. It is estimated that the Namaska mine will produce an annual lithium output of 34,000 tonnes by 2025, and that number could eventually rise to 100,000 tonnes annually (Scheyder, 2022).

Sayona Quebec, which is reopening the second lithium mine in the region in the community of La Corne after acquiring it in 2021, is also planning to develop new mines and to establish refining operations in the region. Other projects in northern Ontario are currently in their early

doi:10.6342/NTU202300492

stages of development, such as the PAK project led by Frontier Lithium which owns lithium hard rock resources.

4.1.3. Financing Canadian Lithium

For resource extraction industries such as lithium, politics are intimately linked to project financing. The support, both moral and financial, as well as the predictability of governments exercises a significant influence on the likelihood of success of domestic extraction operations. Furthermore, stable rules-based systems support the success of more predictable and accountable commercial institutions, and ultimately provide better access to capital.

Despite defending values of sustainable development and environmental protection, both the political left and right in Canada are strong advocates for resource development considering its significance in the nation's gross domestic product (GDP). The Canadian government tightly regulates resource development but it also heavily subsidises it, playing a large role in de-risking early stage mining projects and attracting greater levels of investment (Chagnon, 2022). This in turn contributes to Canadian lithium's attractiveness in the global market. In 2022, the Canadian government announced CAD 4-billion in support to critical mineral development (Rajagopal, 2022). Canada plays a significant role on the world stage in advocating and developing policies for the development of critical mineral resources, including lithium.

The risk that a Canadian government and its leadership might act erratically, autocratically and in a way that doesn't abide by international standards, regulatory frameworks and general rules-based order has historically been low in Canada. The nation is a strong supporter of such rules-based order and actively participates in many collaborative and multilateral agreements with nations around the world. This strengthens the confidence of investors when investing in Canada. The Canadian federal government's predictability and support of resource extraction industrial

doi:10.6342/NTU202300492

activity is not expected to waver dramatically from one election cycle to the next. This reality may even be considered as a strategic advantage on a global scale as it differentiates Canada's supply on the global lithium market.

Regarding the stability of capital markets, Canada is typically regarded as a friendly and secure market for investors, including for foreign direct investment (FDI). However, the government has had a history of intervening and ordering divestments from certain firms when a national security threat is perceived. Such interventions have mainly been targeting investments made by Chinese state-owned ventures, but it is reasonable to assume that under different circumstances, the Canadian government could also intervene in investments by actors from different states. This poses a notable risk to some Canadian lithium project proponents which may find themselves limited to raising capital from sources approved by the federal government.

Canada's relationship with China is a recurring issue in its lithium ambitions. Both nations have had political differences in recent years and the Canadian Government has repeatedly interfered in its domestic lithium sector to counter strategic moves carried out by state-owned Chinese firms. The Canadian Government recently ordered that Chinese firms divest from three Canadian firms engaged in lithium production activities, stating national security concerns. This intervention is likely to deter future Chinese foreign direct investment into Canadian lithium going forward which raises concerns regarding financing for Canadian lithium firms. The three firms from which China's divestment was ordered are expecting the Canadian Government to suggest alternative sources of capital to complete their respective projects, and some have stated that they are considering legal action against the government (Bennett, 2022).

Beyond FDI, Capital markets in Canada remain easy and secure trading platforms for investors. Canada's mining sector attracts significant levels of investment on its domestic TSX

doi:10.6342/NTU202300492

and TSXV exchanges, which are stable and transparent capital markets for publicly listed companies. In 2022, mining firms raised CAD 3.1 billion on the TSX and TSXV, representing 25% of total investments made on these exchanges this year (Rajagopal, 2022). In 2021, mining firms accounted for 18% of total investments made on these exchanges, which were 54% higher under better economic circumstances. Mining interests raise capital easily on these markets in Canada, and lithium firms have been benefiting from especially high levels of investment in Canada given the quality of its lithium resources and the prospects of global lithium demand. Some even state that there is too much capital being invested in Canadian lithium firms, and that many risky ventures are expected to fail while others will experience tremendous success (Chagnon, 2022).

Lithium's national security implications have led to it becoming a geopolitically sensitive industry. The evolving context provides an opportunity for Canada to position itself for success in a market dominated by two diverging political systems. Stable capital markets and government intervention in the capital structure of Canadian lithium projects are two ways supporting Canadian lithium interests.

4.1.4. Supply Chain Transparency

Supply chain transparency plays a major role in supporting stability in the lithium market. End-users of lithium are primarily engaged in businesses that operate under an expectation of sustainability, such as the EV battery manufacturing market. As a result, sourcing and other business operations are subjected to ESG policies that shape lithium demand. Transparent supply chains ensure that the raw material inputs of EV batteries, for instance, meet such requirements, providing greater levels of confidence and of stability to the market. The accountability of both

doi:10.6342/NTU202300492

lithium producers and EV battery manufacturers resulting from transparent supply chains also contributes to reducing volatility in these sectors.

Lithium supply chains are expected to provide transparency in large part because battery supply chains are required to. There are a number of institutions that are invested in increasing transparent battery supply chains for the benefit of the industry and of other stakeholders. The World Bank, for instance, has developed an online platform called the Climate Mineral Explorer to better measure greenhouse gas emissions across mineral supply chains. This platform namely provides users with scenarios to optimize the flow of minerals across the supply chain (Morreia, Pannetier, Parera, 2022). The Global Battery Alliance is another institution in this space which is committed to ensuring greater EV battery supply chain transparency in the name of environmental and social sustainability. It has developed a Battery Passport program which supports this objective throughout the manufacturing process and across the battery's lifecycle. These institutions and the solutions for supply chain transparency they propose are actively contributing to reducing risk in lithium sector.

4.2. Economic Factors

Lithium markets are affected by a number of micro and macroeconomic risk factors. Even though many such risk factors are common to every industry, their specific impact on the lithium market is largely a function of the geography of supply. Following the discussion on the geopolitics of lithium, geography is equally an indicator of economic risk.

doi:10.6342/NTU202300492

4.2.1. Geography and Economic Viability

The geographic location of identified lithium resources and of active production is important when characterising lithium supply for a number of reasons, the first of which is the cost of extraction. Similarly to oil and gas resources, production costs for lithium will vary based on the nature of the source - brine or hard rock - and also on the physical geography and the location which either support or hinder industrial activity and transportation. For instance, extracting lithium from brine in flat and easy to access desert environments is more cost effective than establishing new hard rock extraction activities in mountainous and out of reach regions of Canada. Infrastructure development in a given country plays a significant role in driving resource extraction costs either up or down, regardless of the sector. Geography is also important when considering the location of both suppliers and end users of lithium and how distribution networks may affect bottom lines.

Canada is especially vulnerable to commodity price fluctuations because of its geography. Available resources are often located in remote regions of the country where infrastructure is non-existent, driving up the initial capital requirements of new projects and their ongoing operational expenses, not to mention ensuring the availability of qualified workforce and related social services. The breakeven price point of most Canadian resource production is thus typically higher than most other markets around the world. This has been the case for Canadian oil and gas and is currently the case for Canadian lithium.

Despite regionalized production, lithium is a globally traded commodity that is subjected to the sway of pricing. Lithium prices have had and will continue to have a decisive impact on Canadian production, just as is the case with other commodity markets in which Canadian firms are engaged. Canada’s economy is heavily invested in resources extraction and raw materials and

doi:10.6342/NTU202300492

many of its activity sectors and communities have historically been subjected to boom and bust phases that were largely dictated by price fluctuations.

4.2.2. Lithium Prices

In a general sense, prices and their volatility over time paint a clear picture of the dynamics of demand in any industry. In the case of lithium, prices have historically demonstrated just how significant the demand for lithium is expected to become as the world accelerates its adoption of EVs. In November 2022, the price per metric tonne of lithium peaked at CNY 590,000, up 194% from a year prior and the highest ever recorded by assessment agencies (Tang, Chen, 2022), following an 24-month upwards trend in prices. Fluctuations of both lithium carbonate and lithium hydroxide prices have also been generally aligned. Lithium price volatility has been increasing in recent years due to strong demand and major investments in new supply. After a spike in prices around CNY 154,000 per metric tonne in 2017 driven by battery demand across various industries, prices dropped into 2018 as new production announcements from Australia were made (Natural Resources Canada, 2022). Prices continued to drop to almost CNY 30,000 until 2020 and then increased demand for EVs shot prices up again to CNY 308,000 by the end of 2021 and continued to where they are now in late 2022, close to CNY 600,000.

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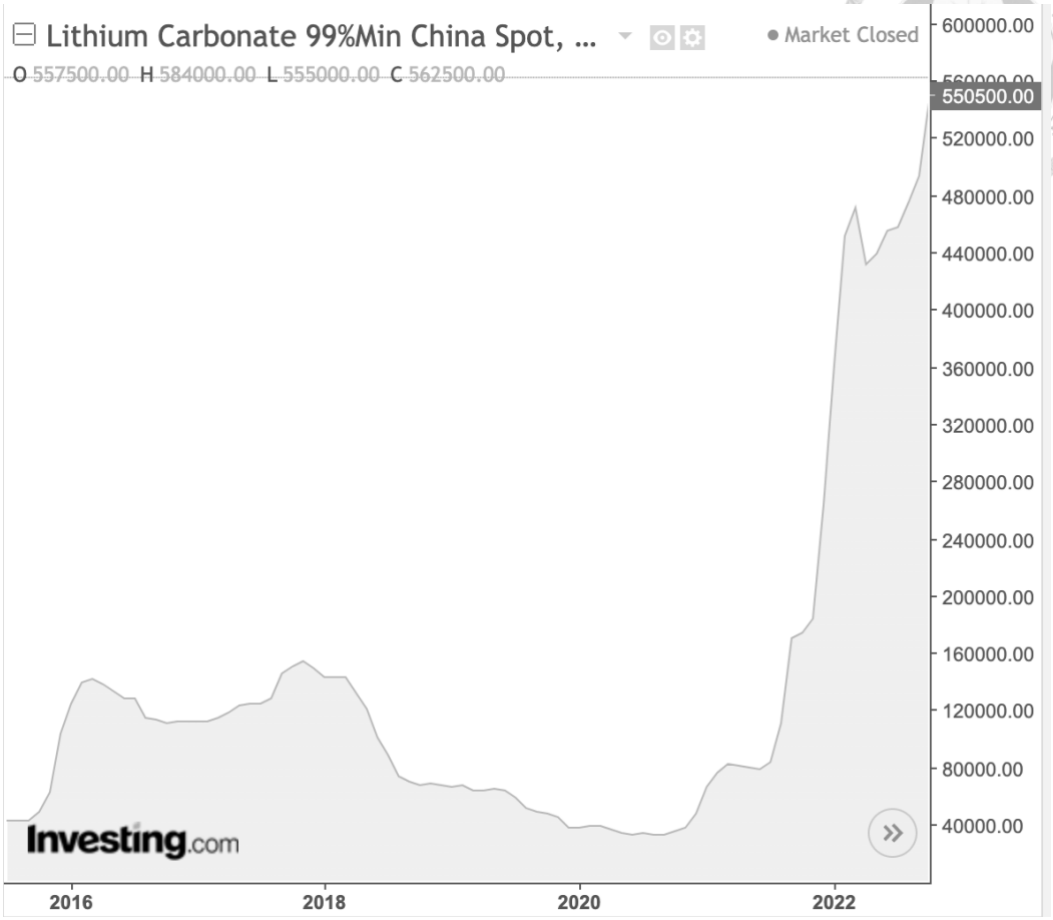
Figure 6: Price of Lithium Carbonate in CNY (2016-2022)



Note. Sourced from: Investing.com. (2022). Lithium Carbonate 99%Min China Spot. https://ca.investing.com/commodities/lithium-carbonate-99-min-china-futures-streaming-chart/ (Accessed 2022-11-25)

This price dance seems to be abidingly led by the market's expectation of future demand, which fluctuates first and foremost as a result of EV sales forecasts, and then also by the availability of prospective supplies. Fluctuations in lithium commodity prices typically have a more profound impact on Canada's national market than it does on the whole world's production as Canada's cost of production is generally higher than in other markets. Low prices make production economically unviable, and therefore Canadian lithium production is more vulnerable to downwards price movements. Price prospects remain good as demand will be fuelled by the

doi:10.6342/NTU202300492

energy transition, and once production operations will have become streamlined and additional infrastructure will be in place, Canada's overall sensitivity to global lithium prices will drop slightly.

4.2.3. Supply and Demand

Overall, the economic risk inherent to Canadian lithium production is considered moderately high largely due to these price fluctuations resulting from shifting supplies and hard to predict demand forecasts. Demand levels are primarily driven by battery manufacturing as a core component of EV battery manufacturing. Demand forecasts vary wildly for the foreseeable future as they depend on a variety of driving forces, however, the research confirms that all forecasts are optimistic and it is only the degree of optimism which diverges from one set of observations to the next.

Furthermore, Quebec-based lithium producers also seem confident that demand for EV batteries will soon be outpaced by demand for general energy storage applications designed for buildings and grid stability, all of which will drive the demand for lithium upwards even more significantly than current forecasts predict (Bourassa, 2022). Risk related to demand fluctuations affect the global lithium sector, but the overall risk to the Canadian sector is deemed low-moderate as it remains a challenge to plan production based on uncertain levels of demand. Nonetheless, demand will remain high and Canadian producers will benefit from being located near the United States which is one of the world's largest EV battery markets.

As one part of the world increases its production capacity, it generally hinders the value of the overall supply from other markets. This was the case for Quebec-based lithium production that shut down and sought bankruptcy after prices dropped as a result of vast new supplies being announced in Australia. Refining capacity also affects overall supply, and has thus far provided

doi:10.6342/NTU202300492

significant leverage to China which supplies the majority of the world's refined lithium. Quebec-based lithium firms are actively investing in local refining capacity and will soon be in a position to operate the full lithium supply chain within its borders. In the North American context, Canada also has access to additional quantities of lithium resources that are under development.

One silver lining for lithium investors among the volatility of supply and demand levels is that this commodity market demonstrates low sensitivity to shifting macroeconomic conditions. The demand for lithium, so far, appears to have been immune to the recent economic downturn as it continues to ride on the momentum of widespread EV adoption and the global energy transition. While other activity sectors have performed negatively on global stock markets in 2022, Canadian lithium firms have been attracting more investment than ever (Chagnon, 2022). It may be expected that if economic conditions were more favourable, the lithium sector in Canada might draw even more capital from global markets.

4.3. Sustainability Factors

Sustainability interests are the main driving force behind lithium demand by extension of the growing demand for EV batteries and other clean and renewable energy applications. Sustainability concerns related to lithium production are therefore a major issue for many of the industry's investors and stakeholders. In turn, these concerns hinder the development of new supply to meet this demand. Environmental, Social and Governance (ESG) issues loom over lithium market dynamics by increasing risk, both economic and reputational in nature.

The ESG landscape of lithium reveals risk areas that have the potential to disrupt the success of new and existing lithium ventures. Ignoring these risks can cause environmental and social damage generating significant foreseen costs and unforeseen costs. Understanding the ESG

doi:10.6342/NTU202300492

landscape can also lead to new business opportunities and process improvements that increase the value of lithium ventures.

A notable example for ESG in the lithium sector is the case of Bolivia, in a region of the world where lithium production is in a more mature state. ESG concerns are the main reason why Bolivia's Salar de Uyuni, the world's single largest lithium reserve, remains largely undeveloped. Extracting lithium from brine would pose extreme environmental stress to this subregion of the Atacama desert. The health, wellbeing and livelihoods of neighbouring communities are also all put at risk by the scale of potential lithium-based industrial development in this region. Ownership and compensation rights for lithium production in this region are also highly contested topics in Bolivia which have decisive implications on how the governance of lithium production would benefit the nation's population (Rochabrun, 2022).

The conversation surrounding ESG in lithium production is split into two broad sets of arguments. The first is more of a philosophical debate regarding the morality of developing one non-renewable resource, lithium, to ultimately support plans that seek to limit the use of another, fossil fuels. The lithium sector has largely branded itself as supportive of sustainability by aligning itself with the EV battery industry, however most lithium industrial processes remain harmful to the environment. While some experts view lithium as a lesser of two evils and a necessary part of enabling global energy transitions, others view its production as counterproductive and encourage leveraging other ways to meet global decarbonization objectives. Generally speaking, more minerals are required in the production of renewable energy-based applications than in the production of fossil fuel-based ones (IEA, 2022), as can be observed in Figure 7.

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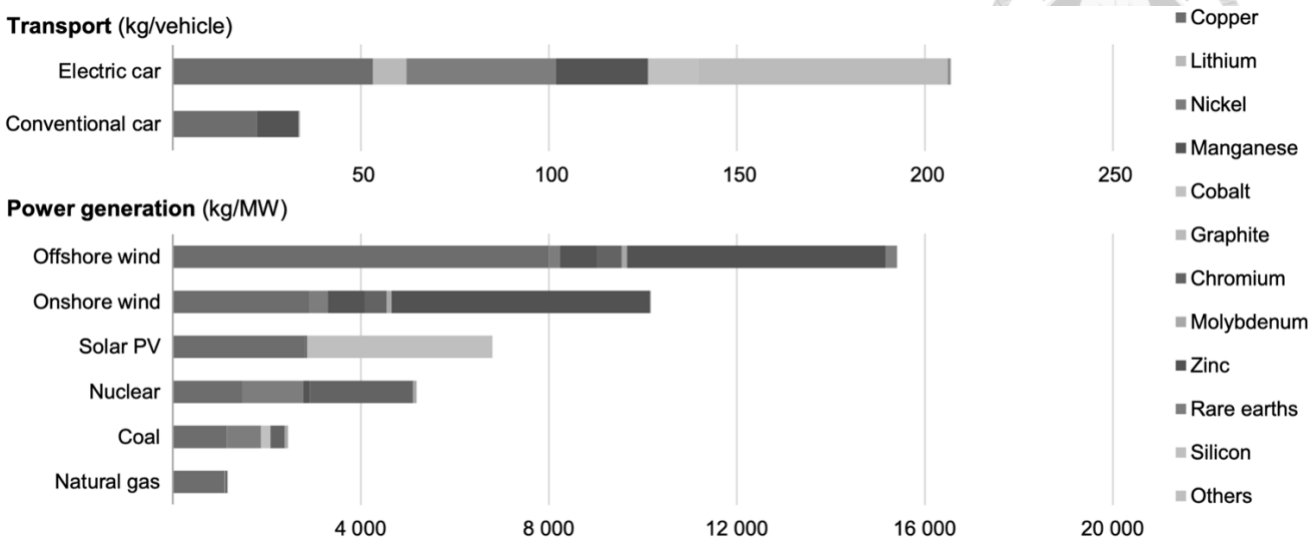
Figure 7: Minerals Used in Selected Clean Energy Technologies



Note. Sourced from: International Energy Agency. (2022). The role of critical minerals in global energy transitions, https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions/ (Accessed 2022-09-20)

The second discussion is more technical, pertaining to tangible and observed impacts of lithium production on the environment and on its stakeholders. Although more sustainable sources of extracting lithium are being investigated, notably geothermal power plant brine and battery recycling, the current dominant sources - saline groundwater brine and spodumene ore - are both harmful to their respective environments.

As a result, the upfront environmental impact of producing one EV is more significant than it is for the production of a combustion engine vehicle. When considering theoretical global lithium reserves, it is highly unlikely that there will be a shortage of lithium to meet the demands of a more energetically sustainable future. However, whether these supplies can constructively support energy transitions by being extracted in truly sustainable ways is front of mind for much of the industry and its investors, and these concerns will be reflected in the strategic planning outlined for lithium development in the coming decades.

doi:10.6342/NTU202300492

4.3.1. Environmental Footprint

Hard rock mining is the most carbon-intensive lithium extraction process delivering 15,000 kg of CO2 into the atmosphere for every tonne of lithium produced, compared to 5,000 kg of CO2 for a brine-extracted tonne. Land and water, however, are more affected by brine-based lithium production. Generating one tonne of lithium from brine involves 3,124 square-metres of land and 469 cubic-metres of water, compared to 464 square-metres of land and 170 cubic-metres of water (Early, 2020). For perspective, the battery of one Tesla Model S vehicle requires 12 kg of lithium, which translates into 60-180 kg of CO2 emissions and 2-5 cubic-metres of water used for each unit produced, depending on how the lithium was sourced.

Lithium extraction poses additional stress on the health of nearby communities and biodiversity by using hazardous chemicals in its processes that contaminate local water and air (Shokeen, 2021). Companies are liable for the environmental risk posed by the use of such chemicals, pursuant to the Canadian Environmental Protection Act in 1999 in that country. Furthermore, unrecycled lithium at the end of its battery's lifetime can also pose a significant threat to soils and waters where it is disposed of.

The Canadian lithium sector positions itself as a provider of a sound supply of lithium from an environmental perspective. This messaging is commonly promoted by lithium firms themselves and by the local municipal and provincial governments where they operate. While Canada and its jurisdictions do have thorough and transparent environmental regulations and monitoring in place for every stage of industrial activity development, sceptics would argue that the appropriate level of regulation is a subjective concept in line with one's degree of inclination toward environmental protection, especially considering that the stakeholders who advocate for resource development are traditionally those who would benefit from it economically.

doi:10.6342/NTU202300492

The environmental regulations governing the mining sector in Canada are enforced at the regional, provincial and national level and involve strict codes and practices that must be abided by and demonstrated from the pre-feasibility phase of a project, to mine remediation accountabilities, including monitoring requirements during its operation,. These standards are taken very seriously in the Canadian lithium sector and in the Canadian mining sector in general, though environmental catastrophe is always at greater risk of occurring than if mines weren't established in the first place.

Beyond the risk of environmental accidents, lithium production involves predictable and quantifiable environmental impacts that are inherent to this type of industrial activity. This includes impacts on local water and air quality and on land use. From a global perspective, this consideration also measures to what extent one supply of lithium may compare to another in terms of supporting global decarbonization objectives. In Canada, most lithium production operations are powered by hydroelectricity, which is considered a mainly sustainable source of power generation. What's more is that Quebec's vast hydroelectric potential contributes to very low energy costs in this lithium-rich province.

Due to the enforcement of local environmental regulations, the overall environmental impact of lithium mining in Canada remains relatively low compared to other markets. As a whole, this industry still produces toxic waste, with local pollution levels increasing with the establishment of new mining operations. Overall, the environmental risk of Canadian lithium extraction, relative to lithium extraction practices in competing markets, is considered to be low, however it remains a very relevant concern for investors.

An example of how environmental factors are a part of the risk assessment for lithium mining is in the Abitibi-Temiscamingue region of Quebec where there is a history of, and now an

doi:10.6342/NTU202300492

even bigger future for, lithium hard rock extraction and transformation. The planned Sayona Quebec mine in the community of La Corne promises considerable economic benefits to the region, however, the mine's reopening has many stakeholders concerned about its history of ownership transfers and the environmentally destructive incidents it led to (McKenna, 2022). Under the mine's previous ownership, two massive waste water spills had caused considerable environmental contamination. Reactivating lithium production threatens the purity of a pristine underground water source that feeds the region's rivers and even serves as the supply for one of the province's largest bottled water companies.

The bottom line is that lithium extraction, be it brine-based or hard rock, involves practices that are destructive to the surrounding environment. In the Canadian context, lithium extraction threatens pristine ecosystems as well as the traditional way of life of Indigenous groups who hold various rights on many of Canada's lithium-rich regions. The degree of acceptability and the perceived trade-offs of the negative effects of lithium extraction are the central questions in this debate.

4.3.2. Indigenous Stakeholders

Social disruptions caused by lithium production in the Canadian context tend to affect Indigenous populations the most as immediate stakeholders. Indigenous groups in Canada are often in fierce opposition to any resource-based extraction occurring on their ancestral lands as it destroys ecosystems and disrupts their traditional way of life. Many even claim it perpetuates colonialist ambitions as outsiders occupy their territory to extract resources destined for export. In today's context, Indigenous groups are very involved in new production developments, are engaged with at every phase of a project and are directly invested in project governance and formally entitled to economic benefits.

doi:10.6342/NTU202300492

In the case of the Sayona Quebec developments, the local Long Point First Nation opposes the project on the grounds that the risk posed by the mine to local ecosystems would significantly disrupt its people's traditional way of life, which still relies heavily on harvesting the land's biodiversity (McKenna, 2022). On the other hand, advocates of the mine defend that the new operation has met all of the current regulations and that regular monitoring activities will be carried out.

Canada has a rocky past with its territory's Indigenous peoples, but is engaged in a committed reconciliatory path forward on the issue of defending their historically undermined rights and land claims. Though many would argue that current initiatives to defend these rights are insufficient, the nation's industries are increasingly sensitive to these issues and are implementing measures to support Indigenous decision-making and benefits as integral components of new and existing resource extraction projects. In the case of the La Corne mine, its historical boom and bust periods dictated by lithium prices lead many locals, Indigenous or not, to question whether the required level of investment and the ensuing risk to the environment are even worth capitalising on the latest unfolding EV battery-led boom period in the first place. ESG concerns therefore pose an ever-present risk in Canadian lithium production as it does across the industry in other parts of the world.

Local opposition from all local community stakeholders beyond Indigenous stakeholders represents another risk area affecting the Canadian lithium sector. In Canada, communities faced with the prospect of mining developments typically view it as both a threat and an opportunity. Pollution and environmental destruction often turn part of the community against such industrial development despite the economic benefits it provides and the investments it attracts. These benefits are often a tempting trade off to other community members, especially in the remote

doi:10.6342/NTU202300492

socioeconomically disadvantaged regions of the country where this type of development typically occurs.

4.3.3. Governance considerations

Defining sustainability-related risks in the lithium sector is also, and perhaps more consequentially, a function of a firm's management of its stakeholders' interests through its approach to governance. As previously presented, the transparency of lithium production activities and the accountability of firms engaged in its extraction and processing both pertain to governance that enables more sustainable policies and practices. From a sustainability perspective, good governance is key to reducing risk.

Sustainability-enabling governance frameworks in the lithium sector also impact the nature and significance of ESG-related costs, which on one hand contribute to reducing sustainability risks, but on the other increase an operation's bottom line. The most tangible ESG cost for most firms is the cost associated with properly reporting on ESG investments and impacts. Another more subjective cost of ESG is the opportunity cost of a given ESG policy (Oosterhoff, 2022). Measuring the trade-offs of investing in mitigating sustainability risk factors is a complex exercise which is intimately tied to crisis management strategies.

In this sense, ESG policies appear to have a greater impact on lithium supply than they do on demand levels. However, ESG policies also have the potential to affect demand levels when lithium buyers, specifically large firms such as those engaged in EV battery manufacturing, enforce supplier selection based on sustainability criteria. This is a way in which lithium demand has the potential to be impacted by ESG policies from within its demand, as EV manufacturers exhibit a greater concern for their environmental impact when it comes to sourcing and supply

doi:10.6342/NTU202300492

chain transparency when compared to traditional combustion engine vehicles. As a result, lithium producers in turn need to invest in ESG policies aligned with those of its main client markets.

4.4. Technological Factors

Technological advancements in lithium extraction have the potential to threaten existing Canadian lithium production by creating new commercially scalable alternatives to traditional brine and hard rock extraction. For the sector as a whole, technological progress represents game-changing opportunities for more sustainable production, new sources of lithium supply, production process improvements and the development of new business opportunities. From this perspective, the risk posed by technology is greater for investors who have not diversified their investments within the lithium sector.

4.4.1. New Sources of Lithium

Innovation in the lithium sector is currently focused on identifying new supplies of lithium that are more cost-effective and more sustainable to produce. Although hard rock and brine-based extraction currently dominate the market, the coming decades could see new alternative sources rise to the top which would both significantly disrupt current lithium supply chains but also generate momentous opportunities for investors and stakeholders alike. Some of these alternative sources include clay, geothermal and waste-based lithium extraction. Introducing these sources into the global supply mix would greatly increase the overall capacity of the market, yielding a direct impact on lithium commodity prices. The quality of the lithium produced from alternative sources has so far on average been lower than that of the lithium extracted from hard rock.

Canada would also potentially have access to alternative sources of lithium extraction even if its existing operations may suffer as a result of this type of development. This reinforces the

doi:10.6342/NTU202300492

notion that for Canada's lithium sector as a whole, the prospect of technological progress in lithium extraction will contribute to reducing risk across the board. However, investors in the short term will be faced with challenging capital allocation decisions as they may choose to target specific competing sources of lithium with their investments rather than all of them simultaneously.

Lithium extraction from oil field brine in the western Canadian province of Alberta has already been identified as a promising and potentially substantial supply of lithium (Lambert, 2022). Output from the lithium brines in western Canada is expected to increase as technological advances enable better lithium extraction from existing oil and gas fields in the region (Natural Resources Canada, 2022). The province of Alberta's lithium brine, though undeveloped, is being considered more economically viable as lithium prices continue to rise. Although the source of Alberta's lithium brine requires technological processes that haven't yet been proven to be commercially scalable, the region's existing infrastructure and workforce associated with its declining oil and gas sector could eventually become one of its strategic advantages in ensuring viable lithium production (Lambert, 2022).

The prospect that technological advancements will make the extraction of lithium from the traditional sources of brine and hard rock faster, more efficient and cheaper is widely regarded as a source of opportunity rather than purely a source of volatility for the Canadian lithium sector. Canada currently relies only on hard rock sources of lithium to produce its national output, which does inject a degree of risk into the continuity of these operations should the technology related to other sources of extraction, such as brine or clay, improve at a faster pace. However, considering the high cost of production in Canada, any progress leading to more cost-efficient production processes will effectively lower risk.

doi:10.6342/NTU202300492

Alternative sources of lithium nonetheless have the potential to replace Canada as a lithium supplier of choice. Additionally, the increased global capacity to supply lithium would also drag lithium prices down, making Canadian production even less valuable in the eyes of the market and of investors. That being said, the reality remains that Canadian lithium production could also benefit from technological progress by making its existing operations more efficient and even by creating new sources of extraction within the domestic market.

4.4.2. Batteries

The future of batteries and energy storage technologies are also intimately tied to lithium production prospects as battery types and mineral compositions play a major role in global lithium demand. Energy storage solutions represent the cornerstone of efficient renewable energy generation and they are also currently the most significant cost component of EV manufacturing.

New compositions of minerals are continuously being tested to optimise battery performance, however, lithium has consistently been at the core of every considered composition. Lithium has been considered the most viable mineral for energy storage solutions for decades despite ongoing research (Bourassa, 2022). Even though quantities of required lithium may increase or decrease per battery unit produced as a result of technological advancements, lithium is expected to remain an essential component of battery manufacturing in the future.

With the advent of all solid-state batteries (ASSB), expected to enter the market between 2026 and 2028, the performance of electrically-powered applications such as EVs will be significantly enhanced (Petrovitch, Chesky, 2019). ASSBs are lithium-based batteries which exhibit less volatility, better control and higher energy density when compared to their liquid lithium-ion predecessors. Despite this anticipated shift in technology, ASSBs will anchor the domination of lithium-based batteries as an energy storage solution of choice for decades to come.

doi:10.6342/NTU202300492

Recycling lithium from batteries is lastly widely viewed as one of the most sustainable and circular supplies of this resource as it would limit the impact of its extraction activities. This poses a considerable risk to existing lithium ventures who engage in extracting lithium from other sources. However, the quantity of batteries currently available on the market which could be recycled to meet world demand is vastly insufficient as the global energy transition remains in its early stages. Lithium recycling from used batteries is expected to play a growing role in lithium markets but its scale and sway over other market factors will be very slow and gradual as the capacity for recycling expands over the coming decades.

These innovation developments taking place in the most significant demand sector for lithium anchors the demand for this resource and even lower risk if investments have been adequately diversified. Lithium is expected to remain the core mineral component of batteries for the foreseeable future and battery technology progress will likely lead to the creation of new market opportunities for investors in lithium..

As a result, the risk that technological progress poses to Canadian lithium operations appears to be moderate in its balance between volatility and opportunity.

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Chapter 5: Risk Chart for Canadian Lithium

Measuring the riskiness of Canada's lithium production is key to establishing whether or not it is deemed a viable source of lithium for the world's demand. The consensus among experts is that at best, the global lithium market is volatile. The expected demand for this mineral is volatile and so is its supply. This volatility can be tangibly observed in lithium prices over time, which spike as expected demand increases and dip as new supply is announced. Other more subjective risk factors also affect the global lithium market.

Following the analysis of the literature on the lithium market external landscape, a series of overarching risk categories were established to better organise the structure the risk factors affecting investments in Canadian lithium. It has been observed that Canada's lithium market risk is specifically vulnerable to risks pertaining to economic, stability, sustainability and technology. These risks have been summarised into the risk chart in Figure 8, where additional more specific sub risks are listed as rows for each of the four broad risk areas based on the results of the conducted research.

The chart's columns demonstrate the scope of each risk as well as their level of impact. The chart's primary use is to list identified risks and measure their impact. This assessment can in turn become the basis to prioritise risks and to develop mitigation tactics.

At the conclusion of this risk assessment, the score attributed to the overall level of risk affecting the Canadian lithium sector is 2.1875, which puts it slightly above low to moderate.

doi:10.6342/NTU202300492

Figure 8: Summary of Canadian Lithium Risk Assessment

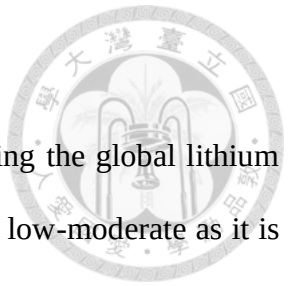
RISK TYPE	SCOPE OF IMPACT	RISK LEVEL	SCORE
Economy			**2.5**
Demand Levels	Global	Low-Moderate	2
Supply Levels	Global	Low-Moderate	2
Prices	National	Moderate-High	4
Macroeconomic Conditions	Global	Low-Moderate	2
Sustainability			**2.5**
Environmental Regulations	National	Low-Moderate	2
Social Disruption	Regional	Moderate	3
Local Opposition	Regional	Moderate	3
Sustainable Production	Global	Low-Moderate	2
Stability			**1.25**
Supportive Government	National	Low	1
Predictable Government	Global	Low	1
Access to Foreign Investment	National	Low-Moderate	2
Stable Capital Markets	National	Low	1
Technology			**2.5**
Existing Sources	National	Low	1
New Alternative Sources	National	Moderate-High	4
Battery Technology	Global	Low-Moderate	2
Recycling	Global	Moderate	3
TOTAL			**2.1875**

5.1. Scoring

The scores presented in the risk chart, pertaining to the scope and level of impact of individual risks, are all substantiated by the results of the conducted research presented in Chapter 4. The rationales for each of the proposed scores are outlined below.

doi:10.6342/NTU202300492

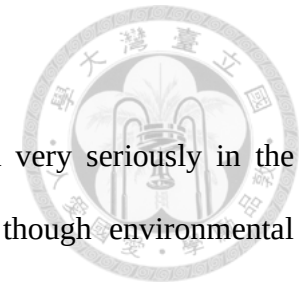
5.1.1. Risk Category 1: Economic Factors



- **Demand levels:** Risk related to demand fluctuations affecting the global lithium sector, but the overall risk to the Canadian sector is deemed low-moderate as it is difficult to plan production based on uncertain levels of demand. However, demand will remain high and Canadian producers are located near the United States which is one of the world's largest EV markets.
- **Supply Levels:** Quebec-based lithium firms are actively investing in local refining capacity and will soon be in a position to operate the full lithium supply chain within its borders. In the North American context, Canada also has access to larger quantities of lithium resources under development. This risk is therefore considered to be low to moderate.
- **Prices:** Low prices makes production economically unviable, and therefore Canadian lithium production is more vulnerable to downwards price movements. Price prospects remain good as demand will be fueled by the energy transition, and once production infrastructure will be in place and operational, overall sensitivity to global lithium prices will drop slightly. As a result, this risk is deemed to be moderate to high.
- **Macroeconomic conditions:** While other activity sectors have performed negatively on global stock markets in 2022, Canadian lithium firms have been attracting more investment than ever, which demonstrates a relative immunity to macroeconomic conditions, making the risk of sensitivity to economic conditions low to moderate.

doi:10.6342/NTU202300492

5.1.2. Risk Category 2: Sustainability Factors



- **Environmental Regulations:** Environmental regulation is taken very seriously in the Canadian lithium sector and in the mining sector in general, though environmental catastrophe is always at greater risk of occurring than if mines weren't established in the first place. As a result, this risk is considered to be low to moderate in the Canadian context.
- **Social Disruption:** The social cost-benefit analysis of the risk posed by lithium production to local Indigenous groups is relatively two-sided, whereby Indigenous stakeholders both oppose and benefit from lithium extraction. This risk is considered to be moderate for Canadian lithium production.
- **Local Opposition:** Pollution and environmental destruction often turn lithium-producing community against such industrial development, whereas the economic benefits it provides and the investments it attracts are often a tempting trade off, especially in the remote socioeconomically disadvantaged regions of the country where this type of development typically occurs. As local opposition is often mixed, this risk is considered to be moderate.
- **Sustainable production:** In Canada, most lithium production operations are powered by hydroelectricity, which is considered a mainly sustainable source of power generation. Due to the enforcement of local environmental regulations, the overall environmental impact of lithium mining in Canada remains relatively low compared to other markets, however, it still produces toxic waste and local pollution levels increase with the establishment of mining operations, leading this risk level to be considered low to moderate.

doi:10.6342/NTU202300492

5.1.3. Risk Category 3: Stability Factors

- **Supportive Government:** Despite defending values of sustainable development and environmental protection, both the political left and right in Canada are strong advocates for resource development considering its significance in the nation's gross domestic product (GDP). The Canadian government subsidizes resource-extraction projects, playing a large role in de-risking early stage mining projects and attracting greater levels of investment. This support is not expected to waver from one election cycle to the next, and as a result this risk is considered low.
- **Predictable Government:** Canada is a strong supporter of a rules-based order and actively participates in many collaborative and multilateral agreements with nations around the world. This strengthens the confidence of investors when investing in Canada, and as a result, this risk is considered low for the Canadian lithium sector. This risk is considered to have an impact on a global scale as its differentiates Canada's supply on the global lithium market.
- **Access to Foreign Investment:** Canada is typically a friendly and secure market for investor, however, the government has had a history of intervening and ordering divestments from certain firms when a national security threat is perceived. As a result, this risk is considered to be low to moderate.
- **Stable Capital Markets:** Canada's mining sector attracts significant levels of investment on its domestic TSX and TSXV exchanges, which are stable and transparent capital markets for publicly listed companies. Mining interests raise capital easily on these markets in Canada, and as a result, this risk is considered to be low.

doi:10.6342/NTU202300492

5.1.4. Risk Category 4: Technology Factors

- **Existing Sources:** Considering the high cost of production in Canada, any progress making production processes less expensive will lower the risk of operations. Furthermore, Canada has identified different sources of lithium resources on its territory, and as a result, this risk is considered to be low.
- **New Alternative Sources:** The quality of the lithium produced from alternative sources has so far on average been lower than that of the lithium extracted from hard rock. Canada would also potentially have access to alternative sources of lithium extraction even if its existing productions may suffer as a result of this type of development. For Canada's lithium sector as whole, all sources considered, this risk is relatively low, although for individual ventures that investors much choose to allocate their capital to, the risk is much higher. This overall risk is thus considered moderate to high.
- **Battery Technology:** New compositions of minerals are continuously being tested to optimize battery performance, however, lithium has consistently been at the core of every considered composition. Even though quantities of required lithium may vary per battery unit produced as a result of technological advancements, lithium is expected to remain an essential component of battery manufacturing in the future, making this risk low to moderate.
- **Recycling:** The quantity of batteries currently available on the market which could be recycled to meet world demand is vastly insufficient as the global energy transition remains in its early stages. Therefore, this risk is considered moderate for the Canadian lithium sector considering the slow-moving disruption it represents.

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Chapter 6: Conclusion

Lithium is one of the most popular commodities embodying the global energy transition. Thanks to its critical role in the functionality of lithium-ion rechargeable batteries, stable and affordable supply of this mineral is essential to meeting the battery demand being steered by widespread EV adoption. Among some of the key supply challenges currently affecting the lithium market are supply shortage to meet the growing demand and the lack of geographic diversification at key points of the supply chain.

Canada, home to a small but significant percentage of world lithium reserves, is poised to turn these challenges into strategic advantages as its domestic lithium sector positions itself to compete on the world stage with other lithium-rich nations. Canada has extensive supplies of identified hard rock lithium that can be processed and sold to its closest market in the United States, which also happens to be one of the world's largest markets. The Americans, deeming lithium as a mineral which is critical to national security, have also been investing in diversifying away their reliance on Chinese lithium supplies, a policy which holds tremendous promise for Canada. Domestically, Canada is a politically stable, investor-friendly, rules and regulations-based and sustainability-oriented economy which can easily brand its supply of lithium as one of the soundest and cleanest in the world, relative to its competitors. Recent investments in domestic lithium supply chain developments are also supporting its prospects in this market.

The conducted research defined the key risk factors affecting Canadian lithium production and largely validated the sentiment that it is a favourable market in which to invest. The main risk factors identified pertained to economics, political stability, sustainability and technology. Political stability and sustainability exhibited lower risk levels overall, whereas economics and

doi:10.6342/NTU202300492

technology revealed the most significant sources of variability and vulnerability over the course of the coming decades.

6.1. Management and Policy Implications

The conclusions of this research suggest that Canada is a low to moderate market in which to carry out lithium investments. This risk level is supported by a series of risks emanating from divergent contextual areas that require specialized methodologies to appropriately measure. Managers who are engaged in decision-making related to lithium will need to surround themselves with in-house or external expertise to properly evaluate the impact of a specific risk area on their business. Understanding the evolving nature of politics and its foreseeable impacts on lithium projects require very different specialists than those who construct models for environmental impact assessments. Being aware of the different risk types and implementing strategies, tools and resources to continuously collect relevant data on these risks should be a priority for any manager investing in lithium.

Furthermore, as is the case with any successful investment strategy, diversification is key to limiting the volatility of returns. When investing in lithium projects, managers should consider both the opportunities and the threats posed by the external environment. Managers should namely consider emerging technologies, global suppliers, alternate sources of lithium and trends affecting key demand sectors for diversification and mitigation purposes before committing to a specific investment path.

Policy-makers involved in the lithium sector should view the identified risk areas as an occasion to turn risks into opportunities. By implementing comprehensive ESG policies, lithium firms can mitigate related risks and generate new business opportunities. By designing policies that account for the global dispersion of lithium supply chains and integrate diversified sourcing

doi:10.6342/NTU202300492

may gain a competitive edge when politically challenging times arise. Enacting policies to allocate resources to research and development efforts and employee development can help smooth the disruption caused by emerging technologies.

Lithium sector managers, policy-makers and investors alike can only benefit from staying informed about the risk areas that affect their businesses and organizations. The defined risk categories and risk chart produced as part of this research represent powerful tools to support this objective.

6.2. Unexpected Findings

Among the unexpected findings of the research was the notion that there is currently too much capital being invested in Canada's capacity for lithium supply. This assessment was made by Xavier Chagnon, who stated during the interview that he expected many junior lithium mining firms who are benefiting from the influx of capital into the market to fail once correction occurs. He didn't perceive this as a looming threat to the sector and was largely optimistic about its prospects. That being said, this view contrasted with some sources consulted during the literature review which stated that some Canadian lithium firms were having a difficult time raising capital to invest in their development projects. The timing of these opposing statements could be to blame in this case. The high proportion of investments in the mining sector on total investments made on the TSX and TSXV exchanges was another unexpected finding of this research, which supports the confidence that the capital markets have in Canadian mining output. Development in the capacity for lithium refining in Quebec and the speed with which regional lithium suppliers expect to acquire market share, especially in the market for lithium hydroxide, is another surprising conclusion.

doi:10.6342/NTU202300492

6.3. Limitations

Some questions remain relatively unanswered by the research. Namely, the true impacts of alternative sources of lithium and of technological innovation in the sector remain difficult to predict as investor confidence appears unwavering in light of the ongoing energy transition. These developments could transform the industry as we know it by the middle of this century. There is a fair assumption that existing lithium operations may be the best positioned to pivot into alternative production processes in due time. Furthermore, China's response to Western diversification efforts is another point of uncertainty at the time of the research. China still dominates the lithium market despite developments in new lithium markets. Its historic lack of transparency, its autocratic government and its extensive lithium and financial resources provide China with the ability to disrupt the market. For instance, it could activate measures to flood the market and drive lithium prices down to deter the development of new lithium production capacity around the world, especially in the supply of refined lithium, where China holds a strategic advantage.

6.4. Future Research

Canada is quickly expanding into a critical supplier of lithium as part of the Western efforts to diversify lithium supplies away from China. Year after year, identified resources have been growing and high levels of new investment and continuous efforts to improve extraction technology is fueling long-term growth in the Canadian lithium sector. Sustained demand will likely keep this market afloat for many decades to come, even if market corrections are expected to slow down the current momentum. With the supply chain investments being carried out in Canada and a new "Battery Valley" emerging in Quebec where automakers such as GM and Tesla are currently establishing battery manufacturing operations in close proximity to lithium reserves

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(Lambert, 2022), Canada is likely to remain an attractive market for investors interested in laying their stake in lithium.

An extension of the research could also include quantifying some of the score attributed to risks in Chapter 5, as they appear in the proposed risk chart. The scores provided in the risk chart represent largely qualitative measurements of risk, whereas obtaining additional data and designing models to produce quantitative impacts for different risks would prove to be even more useful to supporting decision-making in the lithium sector.

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