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# Application of Value Stream Map for Minimization of Wastes in the Supply Chain

A Case Study on the Lithium Industry

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Católica Porto Business School

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## A Case Study on the Lithium Industry

Final Work in Academic Context presented to Universidade Católica Portuguesa to  
obtain the Master's Degree in Management with a specialization in Service  
Management

by

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This thesis is lovingly dedicated to my family, with a special emphasis on my parents and my aunt, whose enduring interest in my endeavors and steadfast belief in my potential have been a constant source of encouragement and inspiration.

*"One day, in retrospect, the years of struggle will strike you as the most beautiful."*

- Sigmund Freud

## Resumo

A metodologia *lean* tem um grande papel no que toca a reduzir desperdícios numa organização, sendo o *value stream map* uma das principais ferramentas desta metodologia que permite identificar desperdícios em matérias-primas e no percurso da informação numa determinada família de um produto.

O presente estudo pretende identificar lacunas na literatura existente através da aplicação do VSM no contexto da extração e processamento do lítio, com foco nas perspetivas Europeias e Portuguesas. Ao analisar os desafios e oportunidades na cadeia de abastecimento do lítio, dando especial ênfase à questão da redução do desperdício e da escolha estratégica de fornecedores. Através do VSM, este estudo aborda o estado atual da cadeia de abastecimento, analisando particularmente as ineficiências relativas à questão do transporte de materiais entre as fases de mineração e refinação, onde os resultados revelam oportunidades significativas para melhorar a eficiência e a sustentabilidade através de intervenções direcionadas.

Nesta pesquisa é ainda destacada a importância da redução de desperdícios no âmbito do alcance de metas de sustentabilidade dentro da cadeia de abastecimento do lítio. Desta forma, recomendações para futuras pesquisas e práticas incluem estratégias para otimizar rotas de transporte, aprimorar processos logísticos e aproveitar parcerias estratégicas de fornecedores de forma a minimizar o impacto ambiental e aprimorar a resiliência geral da cadeia de abastecimento.

**Palavras-chave:** Cadeia de Abastecimento do Lítio, Redução de Desperdício, Escolha Estratégica de Fornecedores, *Value Stream Mapping*, Sustentabilidade.

## **Abstract**

Lean manufacturing plays a significant role in eliminating waste (activities/resources) in a manufacturing organization. Value stream mapping is one of the critical tools in lean manufacturing that will help to identify wastes in materials and information flow in a specific product family.

The study aims to address gaps in existing literature by examining the application of VSM in the context of lithium extraction and processing, with a specific focus on European and Portuguese perspectives. By investigating the challenges and opportunities in the lithium supply chain, with a specific focus on waste reduction and strategic supplier selection, utilizing VSM methodology, the study analyzes the current state of the supply chain, particularly examining transportation inefficiencies between mining and refining stages, where findings reveal significant opportunities for improving efficiency and sustainability through targeted interventions. The methodologies are used to help identify companies in the lithium industry, analyze European countries' use of lithium in battery production, evaluate nearshore strategies, and assess the ecological impact of lithium mining.

Implications of this research feature the critical importance of waste reduction in achieving sustainability goals within the lithium supply chain. In this matter, recommendations for future research and practice include strategies for optimizing shipping routes, enhancing logistical processes, and leveraging strategic supplier partnerships to minimize environmental impact and enhance overall supply chain resilience.

**Keywords:** Lithium Supply Chain, Waste Reduction, Strategic Supplier Selection, Value Stream Mapping, Sustainability.

## **Abbreviations**

APA: Associação Portuguesa do Ambiente

DRC: Democratic Republic of Congo

EU: European Union

LM: Lean Manufacturing

NVA: Non-Value Added

SC: Supply Chain

VA: Value Added

VSM: Value Stream Map

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# 1. Introduction

## 1.1 General Framework

In the field of supply chain management, several key theories and concepts form the understanding of waste minimization and lean practices. This section covers the general framework of this research, discussing foundational theories and principles such as lean management, waste reduction, and Value Stream Mapping (VSM).

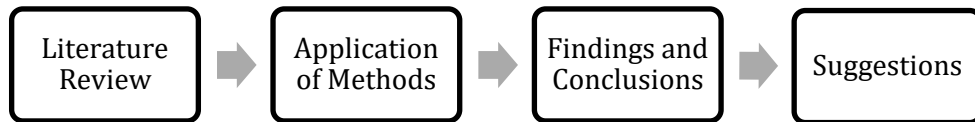
## 1.2 Objectives and Research Methodology

This research is guided by specific objectives and research questions designed to address the challenges of waste minimization in the lithium supply chain. Therefore, this dissertation will aim to answer the following research questions:

- What are the primary challenges and inefficiencies within the current lithium supply chain, and how do they impact the overall performance and sustainability of the industry?
- What strategies can be implemented to enhance the efficiency and resilience of the lithium supply chain, particularly in the context of sourcing, transportation, and processing?
- What are the environmental implications of lithium extraction and processing activities, and how can sustainable practices be integrated into the supply chain to minimize ecological footprints?
- What are the strengths, weaknesses, opportunities, and threats (SWOT) facing Portugal in its endeavor to become a primary supplier in the lithium supply chain, and how can these factors be leveraged or mitigated to optimize value creation?

As seen in Figure 1, the initial phase of this research involves conducting a comprehensive literature review. This critical step entails identifying, analyzing, and synthesizing existing methodologies, concepts, and findings relevant to the research

topic. Following the literature review, the chosen methodologies are applied to identify waste and inefficiencies in processes within the current lithium supply chain. Then, the findings obtained from the application of the chosen methods are analyzed and synthesized to conclude. Ultimately, this research culminates in the provision of forward-looking recommendations for future research endeavors, delineating potential avenues and directions to steer forthcoming studies.



**Figure 1 - Schematic representation of the basic steps of the thesis**

### 1.3 Macrostructure

Following this introduction, this thesis is organized into distinct chapters, each serving a specific purpose.

The first chapter contains the introduction of the dissertation topic, the objective, the research methodology used in its development, and its macrostructure. The second chapter concerns the literature review, intending to understand the progress made so far on this topic. The third chapter defines the problem of the research and its questions. The fourth chapter describes the methods that were used to conduct this study. The fifth chapter concerns the findings. It starts with the dataset characterization, followed by its descriptive analysis, experimentation outcomes, and discussion of results. The sixth chapter contains the main conclusions of this study and areas for potential future works. The last section is the bibliographical references used to support the arguments, concepts, and theoretical foundations throughout the thesis.

### 1.4 Limits

Since this is a scarcely explored topic, the scope of the research is delimited to an in-depth literature review of the existing studies, articles, and other resources available on the topic of lean management, specifically regarding the application of VSM. Moreover, it is relatively rare to find materials discussing practical applications of VSM, especially within the context of the lithium supply chain.

## 2. Literature Review

Upon delving into the study of waste minimization in the lithium supply chain, we realize the necessity for a more profound understanding of the subject matter, particularly regarding its current state of knowledge.

In light of this, this chapter serves two purposes: first, it provides a comprehensive overview of the concepts, theories, and empirical findings that influence our knowledge of waste reduction and supply chain management; second, it critically examines the research and literature that have already been done.

### 2.1 Value Stream Mapping

VSM in the manufacturing environment has been discussed since the technique was used at the Toyota Motor Corporation. It is known as “material and information flow” and can be described as a lean-management method that aims to bring a product or service from a productive beginning to the end customer by analyzing the current state and designing a future state for the series of events (Rother & Shook, 1999).

According to Martin and Osterling (2013) in their book, 'Value Stream Mapping: How to Visualize Work and Align Leadership for Organizational Transformation', and Rother and Shook (1999) in 'Learning to See: Value Stream Mapping to Add Value and Eliminate MUDA', several benefits of VSM are outlined, including the following:

#### **i. Providing a holistic view of the entire flow**

By mapping the value stream, a better understanding of the entire process can be achieved. The act of connecting separate parts into a more holistic system helps the team to identify both the necessary and unnecessary functions, allowing the latter to be either removed or changed for better process flow. VSM also helps to discover any potential information problems that are not easily identified within the production system. By allowing to visualize nonvisible works such as information exchanges it becomes a valuable tool in understanding how the work is accomplished.

#### **ii. Identifying wastes**

Applying VSM to map the current state of the product or service shows value-added and non-value-added processes and waste during the production process. What is more, the value stream map can identify the seven most common types of waste: Overproduction,

Waste	Example
<b>Overproduction</b>	Precast concrete is produced at a level higher than the owner requires. This leads to waste and an increase in inventory and waiting time.
<b>Waiting</b>	Work will be delayed due to broken equipment, and bad weather.
<b>Transportation</b>	Unnecessary movement of information, products, or components from one place to another.
<b>Extra Processing</b>	Following the process accurately eliminates potential costs in installation or rework.
<b>Inventory</b>	Unused products wait for further processing. Poor planning will increase the cost of the worksite and occupy valuable warehouse space.
<b>Motion</b>	Poor material layout will produce unnecessary movements by workers on the work site.
<b>Defects</b>	Defective materials and damaged machines can lead to rework and increase costs.

*Table 1 - Common types of waste*

Waiting, transport, extra processing, inventory, motion, and defects, all of which are summarized in Table 1.

### 2.1.1 Value Stream Mapping Principles and Tools

As previously mentioned, VSM originates from Toyota’s material and information flow diagrams and was designed to help Toyota’s suppliers learn the Toyota Production System (Rother et al. 2003). Rother’s study, along with ten years of experience operating VSM in various industries, has demonstrated that VSM transcends its role as a mere tool for identifying waste. In addition to pinpointing inefficiencies within a system, VSM can also analyze and aid in the design of processes, trace material flow, and document information flow for a given product or product family. Utilizing symbols, VSM represents a clear and visual process from the customer’s requirements to the final accomplishment. Tables 2 to 5 display the several types of symbols used in VSM.

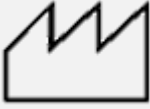
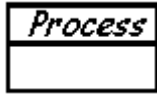
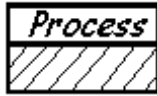
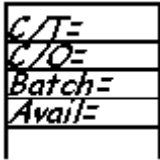

Process Symbol	Meaning
 <p><b>Customer/Supplier</b></p>	Represents the Supplier when in the upper left, the customer when in the upper right, the usual endpoint for the material.
 <p><b>Dedicated Process Flow</b></p>	A process, operation, machine, or department, through which material flows. Represents one department with a continuous, internal fixed flow.
 <p><b>Shared Process</b></p>	A process, operation, department, or work center that other value stream families share.
 <p><b>Data Box</b></p>	It goes under other icons that have significant information/data required for analyzing and observing the system.
 <p><b>Workcell</b></p>	Indicates that multiple processes are integrated into a manufacturing work cell.

Table 2 - VSM Process Symbols (Strategos, 2007). VSM Symbols & Icons. Retrieved from: [http://www.strategosinc.com/vsm\\_symbols.htm](http://www.strategosinc.com/vsm_symbols.htm)

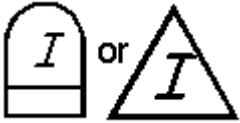
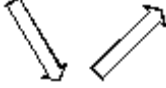

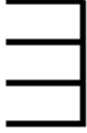



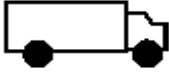
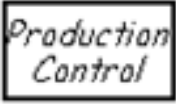
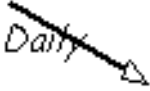




Material Symbol	Meaning
 <p><b>Inventory</b></p>	<p>Show inventory between two processes. It can also represent storage for raw materials and finished goods.</p>
 <p><b>Shipments</b></p>	<p>Represents movement of raw materials from suppliers to the receiving dock/s of the factory/the movement of finished goods from the shipping dock of the factory to the customers.</p>
 <p><b>Push Arrow</b></p>	<p>Represents the “pushing” of material from one process to the next process.</p>
 <p><b>Supermarket</b></p>	<p>An inventory “supermarket” (kanban stockpoint).</p>
 <p><b>Material Pull</b></p>	<p>Supermarkets connect to downstream processes with this "Pull" icon that indicates physical removal.</p>
 <p><b>FIFO Lane</b></p>	<p>First-In-First-Out inventory. Use this icon when processes relate to a FIFO system that limits input.</p>
 <p><b>Safety Stock</b></p>	<p>Represents an inventory “hedge” (or safety stock) against problems such as downtime, to protect the system against sudden fluctuations in customer orders or system failures.</p>
 <p><b>External Shipment</b></p>	<p>Shipments from suppliers or to customers using external transport.</p>

Table 3 - VSM Material Symbols (Strategos, 2007). VSM Symbols & Icons. Retrieved from: [http://www.strategosinc.com/vsm\\_symbols.htm](http://www.strategosinc.com/vsm_symbols.htm)

Information Symbol	Meaning
 <p><b>Production Control</b></p>	<p>Represents a central production scheduling or control department, person, or operation.</p>
 <p><b>Manual Info Icon</b></p>	<p>A straight, thin arrow shows the general flow of information from memos, reports, or conversations. Frequency and other notes may be relevant.</p>
 <p><b>Electronic Info Icon</b></p>	<p>Represents electronic flow such as electronic data interchange (EDI), the Internet, Intranets, LANs (local area network), and WANs (wide area network). You may indicate the frequency of information/data interchange, and the type of media used, ex. fax, phone, etc., and the type of data exchanged.</p>
 <p><b>Production Kanban Icon</b></p>	<p>Triggers production of a predefined number of parts. Signals a supplying process to provide parts to a downstream process</p>
 <p><b>Withdrawal Kanban Icon</b></p>	<p>Represents a card or device that instructs a material handler to transfer parts from a supermarket to the receiving process. The material handler (or operator) goes to the supermarket and withdraws the necessary items</p>
 <p><b>Signal Kanban Icon</b></p>	<p>Used whenever the on-hand inventory levels in the supermarket between two processes drop to a trigger or minimum point. It is also referred to as “one-per-batch” kanban.</p>

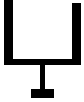





 <p><b>Kanban Post Icon</b></p>	<p>A location where kanban signals reside for pickup. Often used with two-card systems to exchange withdrawal and production kanban.</p>
 <p><b>Sequenced Pull Icon</b></p>	<p>Represents a pull system that instructs subassembly processes to produce a predetermined type and quantity of product, typically one unit, without using a supermarket</p>
 <p><b>Load Leveling Icon</b></p>	<p>A tool to batch kanbans to level the production volume and mix over a period.</p>
 <p><b>MRP/ERP Icon</b></p>	<p>Scheduling using MRP/E.RP or other centralized system.</p>
 <p><b>Go See Icon</b></p>	<p>Gathering of information through visual means.</p>
 <p><b>Verbal Information Icon</b></p>	<p>Represents verbal or personal information flow.</p>

Table 4 - VSM Information Symbols (Strategos, 2007). VSM Symbols & Icons. Retrieved from: [http://www.strategosinc.com/vsm\\_symbols.htm](http://www.strategosinc.com/vsm_symbols.htm)



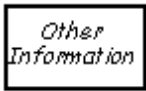

General Symbol	Meaning
 <b>Kaizen Burst Icon</b>	<p>These icons are used to highlight improvement needs and plan kaizen workshops at specific processes that are critical to achieving the Future State Map of the value stream.</p>
 <b>Operator Icon</b>	<p>This icon represents an operator. It shows the number of operators required to process the VSM family at a particular workstation.</p>
 <b>Other Icon</b>	<p>Other useful or potentially useful information.</p>
 <b>Timeline Icon</b>	<p>The timeline shows value-added times (Cycle Times) and non-value-added (wait) times. Use this to calculate Lead Time and Total Cycle Time.</p>

Table 5 - VSM General Symbols (Strategos, 2007). VSM Symbols & Icons. Retrieved from: [http://www.strategosinc.com/vsm\\_symbols.htm](http://www.strategosinc.com/vsm_symbols.htm)

## 2.2 Waste Minimization in Supply Chain

According to Kilger and Stadtler (2005), a supply chain can be broadly defined as two or more legally separated organizations, being linked by material, information, and financial flows. A supply chain's overall goal is often understood to be raising competitiveness. This is because the supply chain, rather than a single organizational unit, is now entirely accountable for the competitiveness of its goods and services in the eyes of the final consumer.

According to Catherine Weetman (2013), the escalating global consumption of finite resources due to population growth and increased consumer demand is leading to higher raw material costs and concerns about resource depletion.

## 2.3 Lithium Industry and Supply Chain

Lithium now plays an essential role in our economic system and is likely to do so in the future (Narins, 2017; Vikström & Davidsson, 2013). It is the key element in energy storage, responding to a highly rising trend of demand for several electronic devices and mostly Electric Vehicles (EVs). According to Tarascon (2010), lithium has been dubbed the "new gold," while Barandiaran (2019) refers to it as the "new oil" or "white gold." The significance of this issue for modern society is underscored by the 2019 Nobel Prize in Chemistry awarded to Goodenough, Whittingham, and Yoshino for their pioneering work on the development of lithium-ion (Li-ion) batteries. The significance of this issue for modern society is underscored by the 2019 Nobel Prize in Chemistry awarded to Goodenough, Whittingham, and Yoshino for their pioneering work on the development of lithium-ion (Li-ion) batteries.

The transition to renewable energy sources and electric vehicles, which demand advanced battery storage technologies, has resulted in a significant increase in the demand for lithium during the last ten years. As seen in Figure 1, batteries are thought to utilize 74% of the lithium used worldwide, which can be considered as one of the top reasons for uncertainty about the availability of enough lithium due to the sharp rise in global demand.

Five primary stages comprise the lithium-ion battery industry chain, which is as follows (Yellishetty et al., 2023):

- 1) Mining for materials.
- 2) Refining and processing.
- 3) Making battery materials.
- 4) Manufacturing the cells.
- 5) Assembling the cells into battery packs.

In the context of the lithium supply chain, characterized by its pivotal role in powering various technologies such as electric vehicles and renewable energy storage systems, this trend is particularly pronounced. The exponential rise in demand for lithium-ion batteries, driven by the transition towards cleaner energy sources, exacerbates pressures on lithium reserves and extraction processes. Consequently, ensuring the sustainability and efficiency of the lithium supply chain is imperative. The application of VSM within this

sector becomes paramount, as it offers a systematic approach to identify and mitigate inefficiencies, optimize processes, and promote resource conservation, facilitating the transition towards a more sustainable and resilient lithium supply chain.

There has been a growing emphasis on the strategic significance of lithium in battery production.

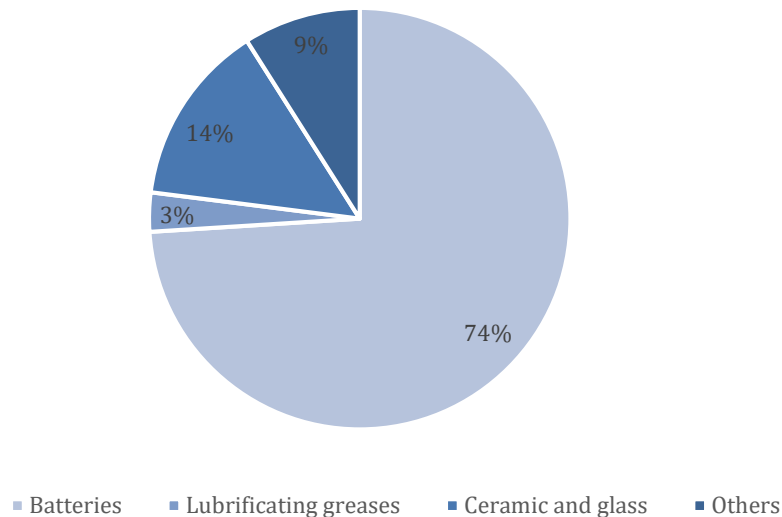


Figure 1 - The proportional uses of lithium.

Source: Innovation News Network. (9th March 2023). Capturing the value of the global lithium supply chain. <https://www.innovationnewsnetwork.com/capturing-value-global-lithium-supply-chain/30827/>

## 2.4 Industry Application of VSM

When scrutinizing the tool's application in the industry, as explored in "*A Structured Literature Review: Value Stream Mapping (VSM) in the Construction Industry*" by Fernandez-Solis and Li (2018), various challenges become apparent within the construction process. These challenges encompass the consumption of unnecessary resources, leading to significant waste, environmental concerns, and heightened levels of customer dissatisfaction. It concludes that while VSM holds potential in construction, it requires rethinking and redesigning to be effectively employed in this industry, referring that adaptations and modifications are necessary to become more effective.

Pasqualini and Zawislak (2005) applied a modified version of VSM, incorporating adjustments at each stage, to optimize the production process within a Brazilian construction company. Similarly, Yu et al. (2009) employed this modified VSM methodology to streamline waste management in housing construction. In this study, the products of production home building were considered as a sole product family due to their shared processing steps and subcontractors. While construction sites lack a traditional production line, workers transition between houses, facilitating a continuous flow of operations. Consequently, the production process for each house was segmented into five stages, considering the size of the value stream map, logical relationships, and total construction duration. These stages encompassed the foundation, lock-up, interior and siding, pre-finals, and finals. Upon identifying the foundation stage as the target for improvement, a current state map was developed, as depicted in Figure 3.

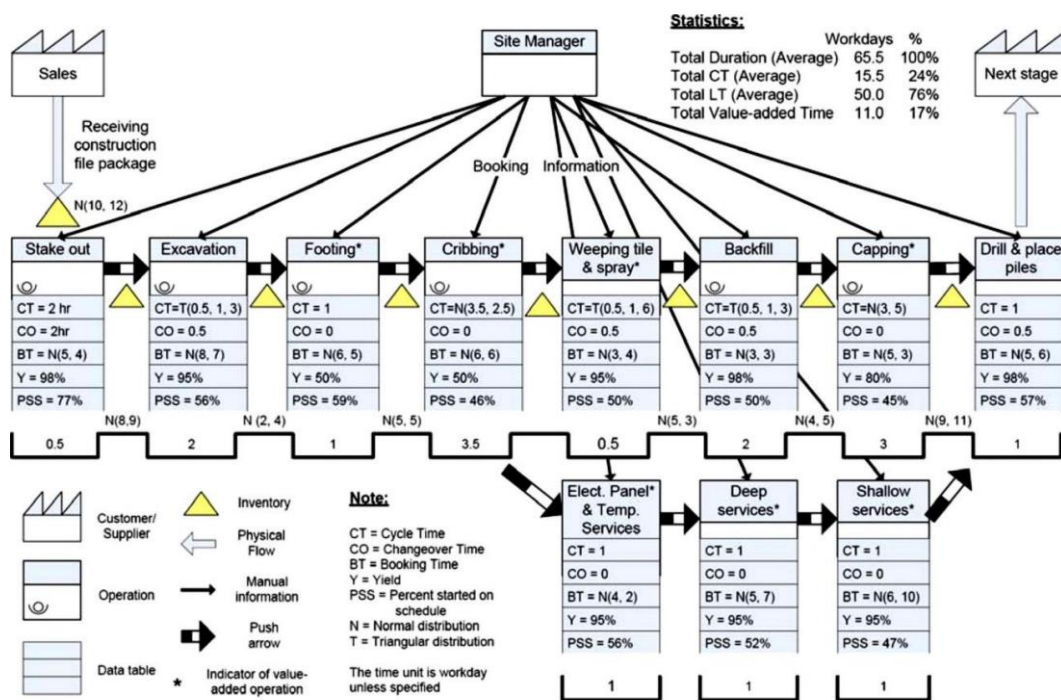


Figure 2 - Current-State Map of Home Building Process (stage 1), Reprinted from Yu et al. (2009)

The development of the future state map follows an analysis of the current state map, during which waste is identified. The primary aim of the future state map is to eliminate the root causes of waste and enhance the value stream to achieve a seamless flow. Four key measures are employed in future state mapping: establishing a production flow

synchronized to Takt Time, leveling production at the pacemaker task, restructuring work processes, and enhancing operational reliability through standardized work practices and total quality management principles. Figure 4 illustrates the future state map.

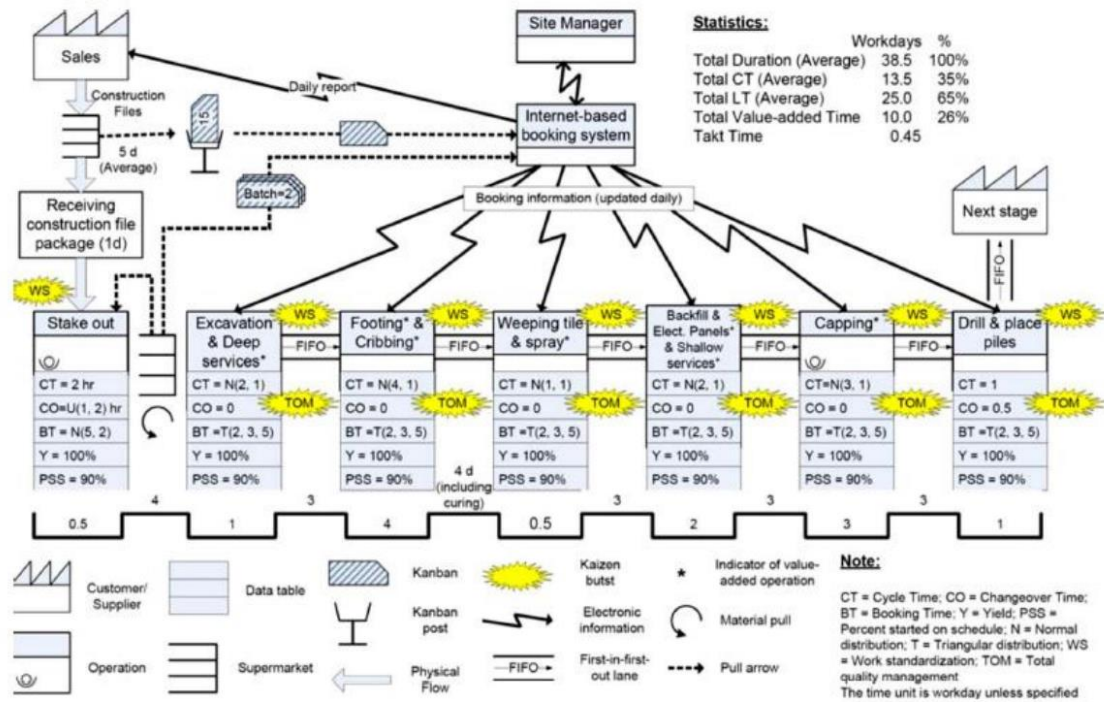


Figure 3 - Future-State Map of Home Building Process (stage 1), Reprinted from Yu et al. (2009)

With these cases, we can comprehend that VSM serves as a tool for pinpointing sources of production waste, quantifying them, and proposing reduction strategies within the construction process.

## 2.5 Environmental Considerations in Lithium Extraction and Processing

The environmental impact being considered is regarding the direct lithium extraction from brines. According to Flexer et al. (2023), lithium is a fundamental element driving sustainable mobility and energy and its mining is therefore under scrutiny and will require social licensing. A major open question regarding the sustainability of evaporitic technology is its intensive water usage. As of 2022, worldwide, eight full-scale active facilities produce lithium compounds from continental brines, and more are likely to become active before 2030. The evaporitic technology is currently in use at seven of those facilities.

## 2.6 The Context of Lithium in Portugal

According to Dias et al. (2021) the context and potential as regards lithium deposits favor Portugal over other European countries (Amarante et al., 2011; Oliveira and Viegas 2011; Viegas et al., 2012; Machado Leite 2017), ranked as the biggest European potential producer, with the largest known European reserves (Carballo-Cruz and Cerejeira, 2020). From an economic/political point of view, this represents an advantage in Portugal's economic strategic mosaic, increasing its global revenue and achieving not only the sectoral independence of a vital resource but also becoming one of its net exporters. That means Portugal may play an important role as a supplier for European companies that will have raw material "nearby", with evident savings in terms of transport costs and favorable supply deadlines.

### 3. Problem Definition and Research Questions

This section addresses the problem definition, as well as the research questions of this dissertation.

#### 3.1 Problem Definition

Several European countries participate in the production and recycling of lithium batteries, with some being more prominent than others. Germany, Sweden, Finland, France, Netherlands, and Poland are among the countries actively working to increase their involvement in the lithium battery industry, including both production and recycling:

1. **Germany:** Germany has a significant presence in the lithium battery industry, with various companies involved in both production and recycling. Companies like Northvolt, a Swedish battery manufacturer, have expanded their operations into Germany through partnerships and the establishment of production facilities. Germany notified the Commission, under the Temporary Crisis and Transition Framework, a € 902 million measure to support Northvolt in the construction of a production plant for advanced and high-efficiency electric vehicle batteries in the city of Heide. The plant will have an annual capacity of 60 GWh. This translates to 800,000 to 1 million electric vehicles per year, depending on the size of the battery. The plant will start producing in 2026 and will reach full production capacity in 2029 (European Commission, 2024).
2. **Sweden:** Sweden is home to Northvolt, one of Europe's leading lithium-ion battery manufacturers. Northvolt is actively involved in expanding battery production capacity in the region.  
"Northvolt raises a \$5bn financing to expand battery cell production." (Editorial Staff, 2024)

3. **Finland:** Finland is another country with a growing presence in the lithium battery industry. Finnish companies like Fortum are investing in battery recycling technologies, aiming to establish a circular economy for batteries.

The process improvement will also help to achieve the EU's stricter recycling rate target and has received funding from the European Union's NextGenerationEU<sup>1</sup> from Finland's sustainable development program. The project will promote Finland as the forerunner of sustainable solutions in the battery industry, support the implementation of the national battery strategy, and the growing battery cluster in Finland, while also strengthening the supply chain of critical raw materials in Finland and Europe (Daniel-Huhtaniska, 2023).

4. **France:** France is home to numerous companies engaged in battery production and research. Notably, the country recently inaugurated its first electric car battery plant in the heartland of its former mining regions, a key component of Emmanuel Macron's "reindustrialization" initiative. The country aims to be self-sufficient in vehicle battery production by 2027. Experts say the challenge could be hampered by China's domination of extraction and production of nickel, cobalt, and manganese elements essential for lithium-ion batteries (Willsher, 2023).

5. **Netherlands:** The Netherlands is also emerging as a hub for battery production and innovation.

LionVolt - a spinout from TNO's Holst Centre in Eindhoven, the Netherlands - is working on solid-state batteries that diverge from the liquid lithium found in conventional lithium-ion devices. These batteries feature a unique composition consisting of a thin film embedded with countless solid pillars, resulting in a patented 3D architecture with a significantly expanded surface area. Compared to lithium batteries, ions within these solid-state batteries traverse shorter distances during charging and discharging processes, facilitating considerably faster performance. Moreover, using a solid material eliminates the risk of battery ignition or explosion, increasing overall safety.

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<sup>1</sup> NextGenerationEU refers to the European Union's €750 billion recovery plan designed to mitigate the economic impact of the COVID-19 pandemic and support the transition towards a greener and more digital economy.

LionVolt further claims its batteries weigh 50% less and provide 200% better performance compared to the most advanced lithium-ion batteries available today. The cells can already be used in wearables, but the company eventually plans to build a gigafactory in Eindhoven to make batteries for EVs (Geschwindt, 2024).

6. **Poland:** Poland plays a leading role in the battery sector supply chain. Lithium-ion batteries already account for more than 2.4% of all Polish exports. The value of exports in the battery sector increased 38-fold over the last six years from around PLN 1 billion (EUR 0.21 billion) in 2017 to over PLN 38 billion (EUR 8.24 billion) in 2022. Poland is the leader of the lithium-ion battery supply chain in Europe and will maintain this position until at least 2027. It also holds a high-ranking place globally (Mazur, 2023).

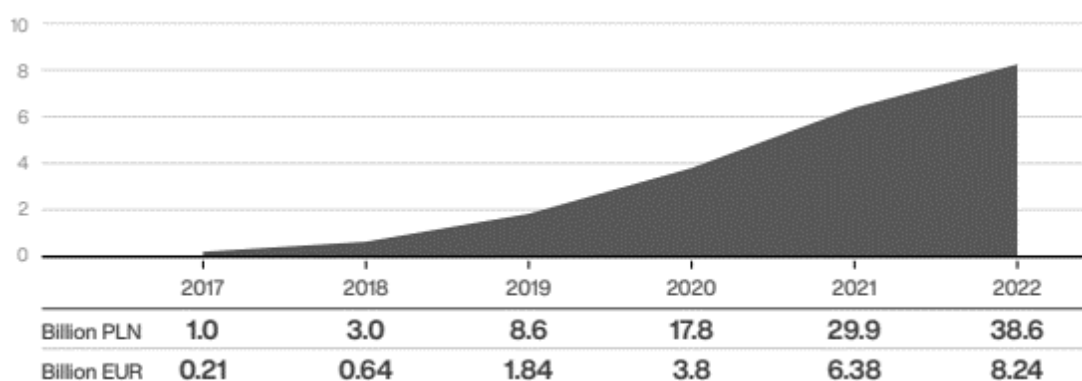


Figure 4 - Export of lithium-ion batteries in Poland | Source: Polish Central Statistical Office

The largest lithium battery factory in the world is currently operating in Poland, launched by LG Energy Solution in Biskupice Podgórne near Wrocław. Its target potential is expected to reach 115 GWh per year. Other leading companies in the battery sector are also investing in Poland and these include Northvolt, Umicore, SK hi-tech battery materials, Capchem, Johnson Matthey, Guotai Huarong, BMZ, and Mercedes-Benz Manufacturing Poland.

Many European companies involved in lithium battery production and manufacturing source their lithium from South America and Asia, particularly from countries known for their lithium deposits and production. Africa also plays a role in the global lithium supply

chain, although to a lesser extent compared to South America and Asia. Some African countries have lithium deposits and are becoming increasingly important in supplying lithium ores and compounds to global markets, including Europe.

The primary goal is to formulate sustainable strategies that minimize waste, enhance operational efficiency, and promote environmentally conscious practices throughout the lithium procurement process and supply chain operations. This section intends to provide an approach towards addressing the mentioned challenges within the lithium industry.

Some of the key countries that supply lithium ores and compounds to Europe include:

### 1. South America

- **Chile:** Chile is one of the world's largest producers of lithium, particularly from the Salar de Atacama region. Companies like SQM (Sociedad Química y Minera) and Albemarle operate lithium extraction operations in Chile.
- **Argentina:** Argentina also has significant lithium reserves, with operations in the Salinas Grandes and Hombre Muerto salars. Companies like Livent Corporation and Orocobre have projects in Argentina.

### 2. Asia:

- **China:** China is both a producer and consumer of lithium. It has invested in lithium mining projects in countries like Australia and has a significant presence in the global lithium supply chain.
- **Australia:** While not in Asia geographically, Australia is a major supplier of lithium to the global market. It has significant lithium reserves and produces lithium compounds. Companies like Talison Lithium (owned by Tianqi Lithium) operate in Western Australia.

### 3. Africa:

- **Democratic Republic of Congo (DRC):** The DRC is known for its significant mineral wealth, including lithium. While the country's lithium production is not as large-scale as other minerals like cobalt, lithium deposits are being explored and developed in the region.

- **Zimbabwe:** Zimbabwe has lithium deposits, particularly in the Bikita Minerals area. The country has potential for lithium production, and there have been efforts to develop these resources.
- **Namibia:** Namibia has lithium deposits, with exploration and development activities underway in areas like the Orange River pegmatite belt.
- **Mali:** Mali also has lithium reserves, and there has been interest from mining companies in exploring and developing these resources.

Due to the abundance of minerals and well-established mining activities in these regions, European industries frequently depend on them for their lithium supplies. They may enter long-term supply agreements or invest in lithium extraction projects in these regions to secure their supply chain for battery production.

European companies may procure lithium ores or compounds from multiple countries as part of their supply chain strategy. However, the extent of this procurement varies based on factors such as deposit quality and quantity, political stability, and regulatory frameworks in each country.

To address the central problem, this thesis presents the distances and route optimization strategies for transporting lithium ores and compounds from various countries via sea and ocean routes. To choose the destination port, we considered various factors such as proximity to industrial centers, infrastructure and connectivity, market demand and competitive advantage. After careful evaluation, Germany emerged as the optimal choice due to its strategic location, robust infrastructure, high market demand for lithium, and competitive advantages in the shipping industry.

To identify potential ports of embarkation in each country, we evaluated their infrastructure capabilities, logistical connectivity, and proximity to lithium mining sites. By consulting maritime industry databases and collaborating with port operators, we compile a comprehensive list of candidate ports for shipping lithium ores and compounds to Germany. For each country mentioned, we identified a port from which lithium compounds could be shipped. The results are as follows:

- Democratic Republic of the Congo (DRC): Port of Matadi

- Chile: Port of Valparaiso
- Argentina: Port of Buenos Aires
- Australia: Port of Melbourne
- China: Port of Shanghai
- Namibia: Port of Walvis Bay

To provide a general idea, container ships, which are among the most common vessels used for sea freight, typically have an average transit speed of around 16 to 24 knots (approximately 18 to 28 miles per hour or 30 to 44 kilometers per hour). This speed can vary depending on the size and design of the vessel, as well as external factors such as currents and weather conditions.

Transit speeds can vary significantly between distinct types of vessels. For example, larger container ships may have higher average speeds compared to bulk carriers or tanker ships. Additionally, vessels may adjust their speed to optimize fuel consumption, comply with regulations, or accommodate specific cargo requirements.

Additionally, shipping times depend on factors such as vessel speed, shipping schedule, and potential delays in ports.

To provide an overview of the approximate distances<sup>2</sup> between the selected countries and Germany we utilized geographic information systems and maritime transportation databases to calculate the distances along sea and ocean routes, considering factors such as maritime currents, navigational obstacles, and geopolitical considerations. Here are the approximate distances<sup>3</sup> between major ports in the listed countries and major ports in Germany:

1. Democratic Republic of the Congo (DRC) (Port of Matadi) to Germany:
  - Port of Matadi to Port of Hamburg: Approximately 5.177 nautical miles, 12 days.

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<sup>2</sup> See more details in the appendix section.

<sup>3</sup> These distances are calculated based on direct routes between ports at a speed of 18 knots and may vary based on actual shipping routes, weather conditions, and other factors.

2. Chile (Port of Valparaiso) to Germany:
  - Port of Valparaiso to Port of Hamburg: Approximately 7.708 nautical miles, 18 days.
3. Argentina (Port of Buenos Aires) to Germany:
  - Port of Buenos Aires to Port of Hamburg: Approximately 6.594 nautical miles, 15,5 days.
4. Australia (Port of Melbourne) to Germany:
  - Port of Melbourne to Port of Hamburg: Approximately 11.364 nautical miles, 26,5 days.
5. China (Port of Shanghai) to Germany:
  - Port of Shanghai to Port of Hamburg: Approximately 10.778 nautical miles, 25 days.
6. Namibia (Port of Walvis Bay) to Germany:
  - Port of Walvis Bay to Port of Hamburg: Approximately 5.798 nautical miles, 13,5 days.

Compared to regions such as South America, Asia, or Australia, Europe lacks significant lithium mining operations. Nevertheless, ongoing initiatives aim to explore and develop lithium resources within Europe. These efforts seek to reduce dependency on imports and bolster the region's position in the global lithium supply chain. Some European countries have existing lithium deposits, while others are actively exploring the feasibility of extracting lithium. These countries include:

1. **Portugal:** Portugal has the largest lithium reserves in Europe and the eighth largest worldwide, according to US geological survey, particularly in the north<sup>4</sup> of the country. There are ongoing efforts to develop these deposits, with several mining projects in various stages of exploration and development.

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<sup>4</sup> See appendix.

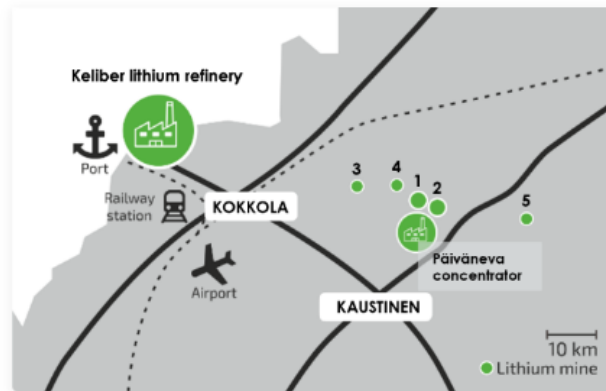
According to EURACTIV, the environment agency APA gave environmental approvals for local company Lusorecursos to extract battery-grade lithium and for London-based Savannah Resources to develop four open-pit mines. Both projects are in northern Portugal. However, local communities campaigning against lithium mining have urged authorities to suspend and review all lithium projects while authorities carry out the investigation and have filed lawsuits to stop mining (Vidal, 2023).

2. **Germany:** Germany has explored the possibility of lithium extraction, particularly from geothermal brines in the Upper Rhine Valley. Research and pilot projects have been conducted to assess the feasibility of extracting lithium from these brines.

According to a report from Think Geoenergy, Vulcan Energy is preparing to launch its Lithium Extraction Optimization Plant (LEOP) in Landau in Rhineland-Palatinate, Germany, to scale up lithium extraction from geothermal water (Cariaga, 2023).

3. **Finland:** Finland has lithium-bearing pegmatite deposits, primarily in the eastern part of the country. Exploration activities have been ongoing, and there is potential for future lithium extraction projects.

On the brink of a monumental shift in lithium supply dynamics, European Energy Metals has announced the granting of the Nabba and Nabba 2 Exploration Licences within the Central Finland Lithium Project, covering expansive areas of 2,780 and 1,740 hectares respectively (Akhtar, 2024).



The five proposed mining sites are:

- |              |             |           |
|--------------|-------------|-----------|
| 1. Syväjärvi | 3. Emmes    | 5. Länttä |
| 2. Rapasaari | 4. Outovesi |           |

Figure 5 - Proposed Mining Sites in Finland | Source: Sibanye Stillwater at <https://www.sibanyestillwater.com/business/europe/keliber/>

4. **Czech Republic:** The Czech Republic has the Europe’s biggest lithium, located in the Cinovec area. Companies have been exploring the feasibility of lithium extraction from these deposits, including through partnerships with other European countries.

The most recent pre-feasibility study showed that 2.25 million tons of ore could be extracted in Cinovec yearly, which would allow to production just under 30.000 tons of lithium hydroxide. According to current estimates, that is enough ore to produce almost one million lithium-ion car batteries a year (Palata, 2023).

5. **Austria:** European Lithium is focused on the development of its wholly owned Wolfsberg Lithium Project, located in Carinthia. The Project is located 20 km east of Wolfsberg, an industrial town, with established infrastructure, including access to the European motorway and railway network (European Lithium).

While these countries have lithium resources, the scale of production is not yet significant compared to other regions. However, with the growing demand for lithium for battery production and efforts to establish a domestic lithium supply chain in Europe, there may be an increased focus on developing these resources in the future.

Given a lithium battery factory in Germany sourcing lithium ores from various countries, including Chile, Argentina, Australia, China, the Democratic Republic of the Congo (DRC), Zimbabwe, Namibia, and Mali, we aim to categorize these nations based on their suitability for onshore, nearshore, and offshore sourcing, considering both mining and extraction capabilities.

To categorize the countries as on-shoring, near-shoring, and off-shoring in the context of a lithium battery factory in Germany, considering the sourcing of lithium ores and extraction capabilities, we can make the following distinctions:

- a. **On-shoring:** These are countries with domestic lithium mining operations and extraction capabilities. Since Germany itself lacks significant lithium resources, we will consider other European countries with mining or extraction operations.
- b. **Near-shoring:** These are countries relatively close to Germany that can provide lithium ores or have extraction capabilities. They may not be in Europe but could still be considered geographically closer compared to other continents.
- c. **Off-shoring:** These are countries located farther away from Germany that supply lithium ores, typically from regions like South America, Asia, and Africa.

Based on these categories and the countries mentioned, we can categorize them as follows:

**On-shoring:**

- Portugal: As a European country with lithium deposits, Portugal could potentially be considered for on-shoring, especially if the lithium can be extracted domestically.

**Near-shoring:**

- Namibia and Mali: These countries are relatively close to Germany compared to other continents. While they may not be in Europe, their geographic proximity makes them viable candidates for near-shoring. Additionally, both Namibia<sup>5</sup> and Mali have known lithium deposits, which adds to their suitability for near-shoring.

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<sup>5</sup> Lithium resources have been identified in Zimbabwe, Namibia, Ghana, the Democratic Republic of Congo (DRC), Mali and Ethiopia (A rush for Lithium in Africa risks fuelling corruption and failing citizens, 2023)

**Off-shoring:**

- Chile and Argentina: These countries, located in South America, are major producers of lithium globally. While they are geographically distant from Germany, they are key players in the lithium market and are often considered primary sources for off-shoring.
- Australia: Similarly, Australia is a significant producer of lithium and possesses vast reserves. Despite being distant from Germany, its robust mining industry and lithium extraction capabilities make it a prominent off-shoring option.
- China: As a major player in the global lithium market, China is also considered an off-shoring option for lithium sourcing. Its significant mining and extraction capabilities contribute to its role as an off-shoring country, despite its distance from Germany.
- Zimbabwe and DRC: Both of these African countries have significant lithium deposits. While they are geographically distant from Germany, they are rich in natural resources, including lithium, and are thus considered as off-shoring options.

In consideration of this, the thesis aims to evaluate Portugal's potential as a primary supplier of lithium ores and compounds to a lithium battery factory in Germany. The focus will be on assessing Portugal's capabilities for value addition within the lithium supply chain, with a particular emphasis on creating a clear and concise value stream map and conducting a comprehensive SWOT analysis, considering necessary investments, as well as ecological and legal issues, to identify risks and opportunities.

### 3.2 Research Questions

To address the challenges within the lithium supply chain, this chapter presents the research questions that will guide the study. In the context of the problem definition outlined in the previous subchapter (3.1), these questions serve as compass points, leading to valuable insights and practical solutions.

- 1. Investigating the Challenges and Key Stages of the Lithium Supply Chain:**
  - a. What are the predominant challenges and inefficiencies characterizing the current lithium supply chain, and how do they influence the industry's overall performance and sustainability?
  - b. What are the distinct stages comprising the lithium supply chain, and how do these stages contribute to the overall dynamics of the industry?
  
- 2. Exploring Opportunities for Optimization and Innovation:**
  - a. What strategies can be implemented to enhance the efficiency and resilience of the lithium supply chain, particularly in the context of sourcing, transportation, and processing?
  
- 3. Sustainability and Environmental Considerations**
  - a. What are the environmental implications of lithium extraction and processing activities, and how can sustainable practices be integrated into the supply chain to minimize ecological footprints?
  
- 4. Strategic Positioning and Competitiveness in the Lithium Supply Chain**
  - a. What are the strengths, weaknesses, opportunities, and threats (SWOT) facing Portugal in its endeavor to become a primary supplier in the lithium supply chain, and how can these factors be leveraged or mitigated to optimize value creation?

## 4. Research Methods

In this section, the research methodology adopted for this study is explained, delineating the approach chosen to address the research questions and objectives articulated previously. Given the nature of the research theme, which focuses on the lithium supply chain, traditional methods such as surveys or interviews were not considered. Therefore, a method involving a comprehensive review and synthesis of existing literature, texts, and documents, alongside a detailed analysis of specific cases pertinent to the theme, has been used to meet this thesis's objectives.

### 4.1 Methods Definition

The selected methodology for this master's final assignment involves utilizing a real-life supply chain management scenario, facilitating an in-depth exploration of operational challenges and solutions. One of the methods that we also use is VSM which, as mentioned before, is a lean management technique used to analyze and improve the flow of materials and information required to bring a product or service to a customer. This methodology helps identify waste and inefficiencies in processes, leading to streamlined operations and improved customer satisfaction. Here are the general steps that we consider while creating a VSM:

1. **Create a current state map:** This step observes the current state of the value stream from beginning to end. This involves mapping out the flow of materials, information, and actions taken at each step of the process. Use symbols to represent different elements such as processes, inventory, transportation, and delays.
2. **Analyze the current state:** Once the current state map is complete, we analyze it to identify waste, bottlenecks, and areas for improvement. Common types of waste include waiting, overproduction, unnecessary transportation, excess inventory, defects, and underutilized talent.
3. **Design a future state map:** Based on the analysis of the current state, we envision and design an improved future state for the value stream. This involves eliminating or reducing waste, optimizing processes, and improving flow to achieve better efficiency and customer satisfaction.

In this thesis, we do not address steps such as implementing improvements, measuring, and monitoring progress, and continuous improvement efforts.

In lean thinking, waste refers to any activity or process that does not add value to the customer or contribute to achieving the desired outcome. These non-value-adding activities are commonly referred to as "Muda" in Japanese terminology.

Our thesis exclusively concentrates on the transportation aspect of lithium ores and compounds. While other types of waste have been identified in a previous chapter, they are not within the scope of our analysis.

Our analysis focuses on two primary stages of the lithium supply chain: the extraction of ores and lithium compounds, followed by the battery manufacturing process. Assuming both mining and extraction take place within the same country, we amalgamate them into a generalized process. Adopting a macroscopic perspective, we intentionally omit intricate process details and focus on overarching steps. Emphasizing the imperative to minimize waste, we designate transportation between these primary stages as an area of concern.

In this study, a SWOT analysis was used as a strategic planning tool to evaluate the strengths, weaknesses, opportunities, and threats associated with Portugal's role as a potential primary supplier of lithium ores and compounds to a lithium battery factory in Germany. The analysis was conducted to gain insights into the current position of Portugal in the lithium supply chain and to develop strategies for future growth and optimization. The SWOT analysis was integrated into the research methodology to provide a structured framework for assessing internal and external factors influencing Portugal's capabilities for value addition within the lithium supply chain.

SWOT analysis is a strategic planning tool used to identify and evaluate the strengths, weaknesses, opportunities, and threats involved in a business venture or project. Here is what we considered in each component of the SWOT analysis:

#### **1. Strengths**

- Portugal's strengths in the lithium supply chain, include its abundant lithium resources, existing extraction capabilities, and strategic geographic location.

- Portugal's potential for value addition by analyzing factors such as available infrastructure, skilled workforce, and research and development capabilities.

## **2. Weaknesses**

- Identification of weaknesses or limitations in Portugal's value-addition capabilities, such as insufficient infrastructure or regulatory constraints, will be a key focus.
- Challenges in the current supply chain that hinder value addition, such as outdated processes or lack of stakeholder integration.

## **3. Opportunities**

- Identification of emerging trends or market opportunities that Portugal can leverage to strengthen its position in the lithium supply chain will be a priority.
- Strategies for expanding Portugal's role in the global lithium market through partnerships or investments in research and development will be explored.

## **4. Threats**

- Potential threats to Portugal's position in the lithium supply chain, such as competitive pressures, regulatory changes, and environmental concerns.
- Mitigation strategies for risks associated with investments in value addition, such as market volatility or geopolitical instability, will also be considered.

In consideration of alternative battery technologies, an overview of notable alternatives such as Nickel-Metal hydrogen (NiMH) batteries, Lead-Acid batteries, Solid-State batteries, Flow batteries, and Hydrogen Fuel Cells was provided. Each alternative was evaluated based on its advantages, limitations, and potential applications. This discussion serves to contextualize the focus on lithium-ion batteries within the research framework and provides insights into the broader landscape of energy storage technologies.

## 5. Findings

This chapter presents the findings resulting from the application of VSM to the lithium supply chain. The aim was to analyze the current state of the supply chain, considering the aforementioned suppliers, identify areas for improvement, and introduce the proposed VSM with Portugal as the supplier to analyze strategic enhancements. The chapter culminates with an analysis of the findings, their implications for the lithium supply chain, and recommendations for improvement.

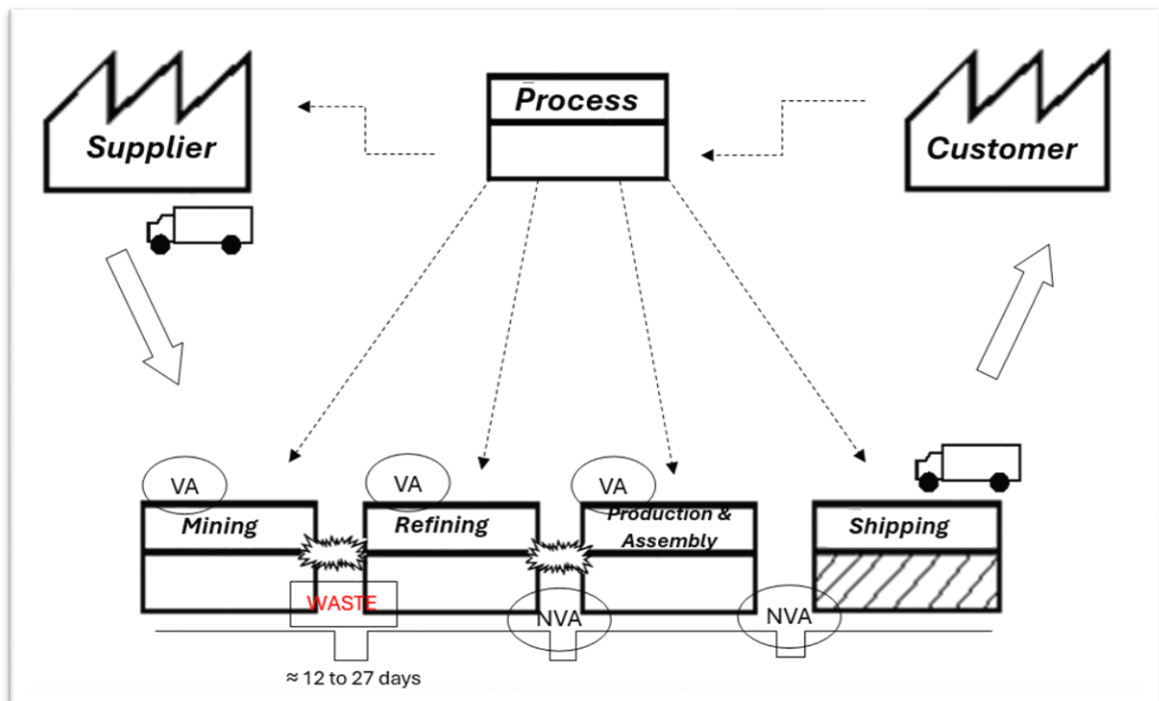


Figure 6 - Current State Map on Lithium Supply Chain | Source: own work

**Legend:**

VA – Value Added Activity

NVA – Non Value Added Activity

The current VSM for the lithium supply chain depicts the flow of materials and information from the customer demand through the various stages of mining, refining, production & assembly, and shipping to the supplier.

Within the process, each stage of the lithium supply chain is outlined. These stages are interconnected, illustrating the sequential flow of activities required to transform raw materials into finished lithium products and deliver them to the customer. The arrows within the process box signify the directional flow of materials and information between the stages.

Value-added activities, such as mining, refining, and production & assembly, are identified within the process box, highlighting the critical steps involved in creating value for the customer. These activities contribute directly to the transformation of raw materials into final products and are essential for meeting customer demand efficiently.

The waste between the stages, indicating potential inefficiencies or non-value-added activities within this transition, is identified as transportation waste. Additionally, the transportation between suppliers, such as the DRC, Chile, Argentina, Australia, China, Namibia, and Germany, is represented, showcasing the distances and transit times involved in shipping lithium from different regions to Germany, varying from 12 to 27 days as calculated previously.

The foundation of this thesis lies in the application of VSM within the lithium supply chain to mitigate waste effectively. Our approach initiated with an analysis of the current state map, identifying areas of waste, and delineating potential areas to improve. After the analysis, **Portugal emerges as the preferred choice to lead as the primary supplier within the lithium supply chain.**

Based on the insights gleaned from our research and analysis, we present a visualization depicting the anticipated future state map. This perspective representation encapsulates the transformative potential of Portugal's involvement as the principal supplier, offering a strategic blueprint for streamlined operations, heightened efficiency, and maximal value creation within the lithium supply chain.

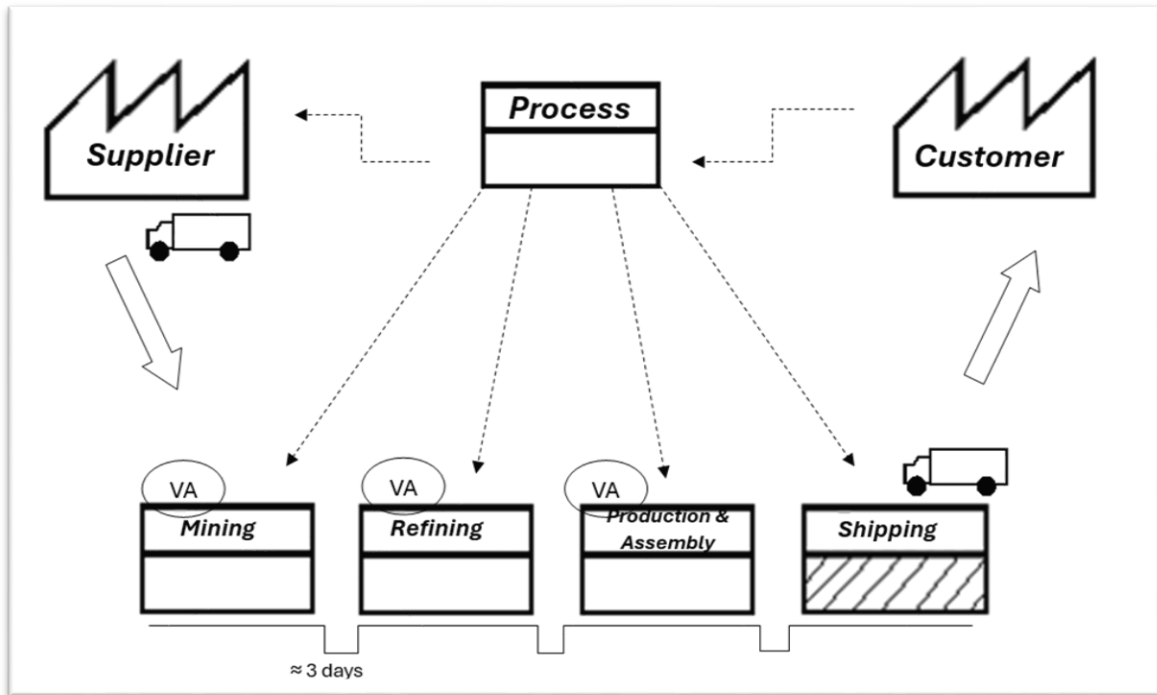


Figure 7 - Future State Map on Lithium Supply Chain | Source: own work

By strategically positioning Portugal as the main key player in lithium supply, our thesis underscores the imperative for stakeholders to embrace this paradigm shift, thereby ushering in a new era of enhanced sustainability, resilience, and competitiveness within the global lithium market.

The following SWOT analysis serves as a strategic tool to evaluate Portugal's competitive positioning and to identify key factors that could influence its success as a supplier in the lithium market. By leveraging its inherent strengths, addressing its weaknesses, capitalizing on emerging opportunities, and mitigating potential threats, Portugal can establish itself as a reliable and strategic partner in the global lithium supply chain.

### SWOT Analysis for Portugal's Value Addition

#### Strengths:

- Abundant Lithium Deposits: Portugal possesses significant lithium reserves, providing a solid foundation for its role as a supplier in the lithium supply chain.
- Stability and Membership in the European Union: Portugal's political stability and membership in the EU contribute to a conducive business environment. Being part

of the EU eliminates trade barriers within the region, fostering smoother trade relations and providing a stable regulatory framework for business operations.

- Strategic Location: Portugal's proximity to Germany reduces transportation costs and lead times compared to off-shore suppliers.
- Established Infrastructure: Portugal has a well-developed infrastructure, including transportation networks and port facilities, facilitating efficient supply chain operations.

#### **Weaknesses:**

- Lack of Infrastructure: Developing extraction and processing facilities may require substantial investments in infrastructure.
- Regulatory Hurdles: Meeting ecological and legal standards for lithium extraction and processing could pose challenges.
- Limited Experience: Portugal may lack experience in large-scale lithium extraction and processing, requiring knowledge transfer or collaboration with experienced partners.
- Environmental Concerns: The environmental impact of lithium extraction activities, such as water usage and habitat disruption, may raise concerns among stakeholders and communities.

#### **Opportunities:**

- Market Differentiation: Becoming the main supplier for the lithium battery factory in Germany could establish Portugal as a key player in the European lithium supply chain.
- Investment Incentives: Government incentives and EU funding programs could support infrastructure development and technology innovation.
- Sustainable Practices: Implementing eco-friendly extraction methods could attract environmentally conscious customers and investors by enhancing Portugal's reputation as a responsible supplier.

- **Technological Advancements**: Advances in lithium extraction technologies and processing methods offer opportunities for Portugal to enhance efficiency and reduce environmental impact.

**Threats:**

- **Competitive Pressure**: Intense competition from established lithium suppliers globally may challenge Portugal's market position.
- **Supply Chain Disruptions**: Geopolitical tensions or natural disasters could disrupt the transportation of lithium ores and compounds.
- **Environmental Concerns**: Stricter regulations or public opposition to lithium mining and processing could hinder operations.
- **Volatility in Global Markets**: Fluctuations in global lithium prices and demand, as well as geopolitical instability, can be a threat to Portugal's economic stability and investment prospects.

**Conclusion:** By leveraging its abundant lithium resources, and investing in extraction, and processing capabilities, Portugal has the potential to add significant value to the lithium supply chain. However, careful consideration of infrastructure development, regulatory compliance, and market dynamics is crucial to mitigate risks and capitalize on opportunities for sustainable growth.

Within this subsection, we present various alternative energy storage technologies, such as nickel-metal hydride (NiMH) batteries, lead-acid batteries, solid-state batteries, flow batteries, and hydrogen fuel cells.

There are several alternatives to lithium batteries, although each alternative has its advantages and limitations. Some of the notable alternatives include:

1. **Nickel-Metal Hydride Batteries**: NiMH batteries have been used in various applications such as consumer electronics and hybrid vehicles. They offer higher energy density compared to traditional nickel-cadmium batteries and are relatively environmentally friendly.
2. **Lead-Acid Batteries**: Lead-acid batteries have been in use for decades and are commonly found in automotive, marine, and stationary applications. They are

cost-effective but have lower energy density and shorter lifespan compared to lithium-ion batteries.

3. **Solid-State Batteries:** Solid-state batteries use solid electrolytes instead of liquid electrolytes found in traditional lithium-ion batteries. They offer potentially higher energy density, improved safety, and longer lifespan. However, they are still in the initial stages of development and commercialization.
4. **Flow Batteries:** Flow batteries store energy in chemical fluids contained in external tanks. They offer scalability and long cycle life, making them suitable for grid-scale energy storage applications. However, they currently have lower energy density and higher costs compared to lithium-ion batteries.
5. **Hydrogen Fuel Cells:** Hydrogen fuel cells convert hydrogen gas and oxygen into electricity and water through an electrochemical reaction. They offer high energy density and rapid refueling, making them suitable for applications such as transportation and stationary power. However, infrastructure challenges and inflated costs hinder widespread adoption.

Regarding whether countries like Portugal should invest in alternative battery technologies, it depends on several factors such as national priorities, technological capabilities, market demand, and strategic goals. Investing in alternative battery technologies could potentially offer several benefits, including:

- Diversification of the energy storage sector, reducing reliance on a single technology.
- Supporting innovation and the growth of the domestic battery industry.
- Addressing environmental concerns and promoting sustainability.
- Contributing to energy security and independence.

Portugal, like other countries, may choose to invest in a diversified portfolio of battery technologies to meet different market needs and capitalize on emerging opportunities. This could include supporting research and development, fostering collaborations between industry and academia, providing incentives for investment and deployment, and creating favorable regulatory frameworks.

Ultimately, the decision to invest in alternative battery technologies should be based on a comprehensive assessment of economic, environmental, and social factors, considering long-term sustainability and competitiveness goals.

## 6. Conclusion and Future Works

This thesis has undertaken an examination of the lithium supply chain, while specifically focusing on identifying and addressing waste and inefficiencies, particularly in transportation between mining and refining stages. Through the application of VSM, we have visualized the current state of the supply chain and identified areas for improvement, highlighting the critical importance of waste reduction in achieving sustainability and efficiency goals.

The findings of this study emphasize the significant impact of transportation waste on the overall performance and environmental footprint of the lithium supply chain. Inefficiencies in shipping routes, logistical processes, and transportation methods contribute to delays, increased costs, and heightened ecological impact, highlighting the urgent need for strategic interventions to mitigate these challenges.

There are several key recommendations and future research directions that emerge from our analysis. Firstly, there is a pressing need for the implementation of targeted strategies to optimize shipping routes, enhance logistical efficiency, and explore alternative transportation methods. By adopting these measures, stakeholders can realize substantial cost savings, minimize environmental degradation, and improve overall supply chain resilience.

Moreover, Portugal emerges as a promising candidate for mitigating transportation waste and serving as a strategic supplier in the lithium supply chain. Leveraging its stable political environment, strategic geographical location, and proximity to major European markets, Portugal has the potential to significantly reduce transportation distances and associated waste, thereby enhancing the efficiency and sustainability of the supply chain.

In addition to the findings presented in this thesis, several considerations for future research and exploration can contribute to further advancements in the field of lithium supply chain management.

Firstly, the alternatives to lithium batteries introduced in this study offer promising opportunities for deeper analysis and evaluation. To determine their long-term viability and potential profitability, future research should focus on conducting detailed assessments of each alternative energy storage technology. These assessments should include comprehensive studies to evaluate factors such as efficiency, performance, sustainability, and economic feasibility across various applications and market contexts. Comparative analyses with lithium batteries can also provide valuable insights into the relative advantages and limitations of each technology, leading to strategic decision-making in the energy storage industry.

Future research efforts should prioritize the analysis and optimization of processes to optimize and reduce waste throughout the lithium supply chain, employing methodologies such as VSM and Lean Six Sigma. By identifying and mitigating various types of waste, including inventory excess, process bottlenecks, and production inefficiencies, researchers can achieve streamlined operations, improved resource utilization, and cost savings across the supply chain.

Furthermore, the integration of advanced technologies and best practices holds significant potential for enhancing supply chain performance and sustainability. Future works should explore the adoption of digitalization, automation, the Internet of Things, and blockchain technologies to enable real-time monitoring, predictive maintenance, and transparent supply chain traceability. Also, the implementation of circular economy principles, renewable energy sources, and eco-friendly manufacturing processes can contribute to reducing environmental impact and promoting long-term sustainability within the lithium supply chain.

In conclusion, the future works outlined in this chapter offer a roadmap for advancing research and practice in the field of lithium supply chain management. Additionally, it would be valuable for future studies to collaborate with real companies, especially if/when Portugal begins to exploit lithium resources, to conduct research and gather firsthand insights into industry practices, challenges, and opportunities.

## Bibliography

- (2023). *A rush for Lithium in Africa risks fuelling corruption and failing citizens*. Global Witness.
- Akhtar, S. (2024). *European Energy Metals Unveils Finland's Lithium Wealth: A Sustainable Path Forward*. Hong Kong: BNN Breaking.
- Barandiaran, J. (2019). Lithium and development imaginaries in Chile, Argentina, and Bolivia. pp. 113, 381-391.
- Cariaga, C. (2023). *Vulcan to open a lithium extraction optimization plant in Landau, Germany*. Think Geoenergy.
- Daniel-Huhtaniska, M. (2023, September 5). *fortum*. Retrieved from forum: <https://www.fortum.com/media/2023/09/fortum-battery-recycling-awarded-grant-45-million-euros-expand-its-mechanical-processing-capacity>
- Editorial Staff. (2024, January 24). *Sustainable BUS*. Retrieved from <https://www.sustainable-bus.com/components/northvolt-financing-5-billion-euros-cells/>
- European Commission. (2024, January 8). *Commission approves €902 million German State aid measure to support Northvolt in the construction of an electric vehicle battery production plant to foster the transition to a net-zero economy*. Retrieved from Official Website of the European Union: [https://ec.europa.eu/commission/presscorner/detail/en/ip\\_23\\_6823](https://ec.europa.eu/commission/presscorner/detail/en/ip_23_6823)
- European Lithium. (n.d.). *Wolfsberg Lithium Project*. Austria: European Lithium.
- Geschwindt, S. (2024, February 12). *The next web*. Retrieved from <https://thenextweb.com/news/dutch-startup-wins-e15m-to-develop-first-solid-state-battery-factory>
- Lia, Y., & Solís, J. L. (n.d.). *A STRUCTURED LITERATURE REVIEW: VALUE STREAM MAPPING (VSM) IN*. Retrieved from <https://core.ac.uk/download/pdf/154406141.pdf>
- Martin, K., & Osterling, M. (2013). *Value Stream Mapping: How to Visualize Work and Align Leadership for Organizational Transformation*. McGraw Hill.

- Mazur, M. (2023, April 7). *Europe runs on Polish*. Warszawa: Polish Alternative Fuels Association. Retrieved from <https://ceenergynews.com/transport/poland-to-lead-the-global-supply-chain-of-the-battery-sector/>
- Narins, T. (2017). The battery business: Lithium availability and the growth of the global electric car industry.
- Palata, L. (2023). *Lithium: The Czech Republic's 'white gold' rush*. Berlin: DW.
- Pasqualini, F., & Zawislak, P. A. (2005). Value Stream Mapping in Construction: A Case Study in a Brazilian Construction Company. *13th International Group for Lean*, (p. 9). Sydney.
- Rother, M., & Shook, J. (1999). *Learning to See: Value Stream Mapping to Add Value and Eliminate MUDA*. Lean Enterprise Institute.
- Stadtler, H., & Kilger, C. (2005). *Supply Chain Management and Advanced Planning*. Hamburg: Springer.
- Tarascon, J. (2010). Is lithium the new gold?
- Vera, M. L., Torres, W. R., Galli, C. I., Chagnes, A., & Flexer, V. (2023). Environmental impact of direct lithium extraction from brines. pp. 149-165.
- Vidal, M. (2023). *A lithium 'gold mine' is buried under one of Europe's last heritage farming systems*. California: MONGABAY.
- Vikström, H., & Davidsson, S. (2013). Lithium availability and future production outlooks.
- Willsher, K. (2023, May 30). *The Guardian*. Retrieved from <https://www.theguardian.com/business/2023/may/30/france-opens-first-electric-vehicle-battery-gigafactory>
- Yellishetty, M., Whittle, D., Hu, R., & Shaibani, M. (2023, March 9). *Innovation News Network*. Innovation News Network. Retrieved from <https://www.innovationnewsnetwork.com/capturing-value-global-lithium-supply-chain/30827/>
- Yu, H., Tweed, T., Al-Hussein, M., & Nasser, R. (2009). Development of lean model for house. *Journal of Construction Engineering and*, 135(8), pp 782-790.

# Appendix

## Appendix A: Port Distances

The distances between ports were determined by utilizing the online platform available at the following web address: <https://sea-distances.org/>.

### 1. Port of Matadi to Port of Hamburg

<b>Port of Departure</b>	<b>Port of Arrival</b>	<b>Result</b>
Country Congo (Democratic Republic)	Country Germany	<b>Direct way</b>
Port Matadi	Port Hamburg	<b>Distance</b> 5177 nautical miles
Vessel speed, knots: 18	<b>Calculate</b>	<b>Vessel speed</b> 18 knots
		<b>time</b> 12 days 00 hours

### 2. Port of Valparaiso to Germany<sup>6</sup>

<b>Port of Departure</b>	<b>Port of Arrival</b>	<b>Result</b>
Country Chile	Country Germany	<b>Way #1</b>
Port Valparaiso	Port Hamburg	<b>Distance</b> 7708 nautical miles VIA Panama Canal
Vessel speed, knots: 18	<b>Calculate</b>	<b>Vessel speed</b> 18 knots
		<b>Time</b> 17 days 20 hours
		<b>Way #2</b>
		<b>Distance</b> 9096 nautical miles VIA Strait of Magellan
		<b>Vessel speed</b> 18 knots
		<b>Time</b> 21 days 01 hours
		<b>Way #3</b>
		<b>Distance</b> 9265 nautical miles VIA Cape Horn
		<b>Vessel speed</b> 18 knots
		<b>Time</b> 21 days 11 hours
		<b>Way #4</b>
		<b>Distance</b> 17510 nautical miles VIA Suez Canal
		<b>Vessel speed</b> 18 knots
		<b>Time</b> 40 days 13 hours
		<b>Way #5</b>
		<b>Distance</b> 18647 nautical miles VIA Cape of Good Hope
		<b>Vessel speed</b> 18 knots
		<b>Time</b> 43 days 04 hours

### 3. Port of Buenos Aires to Port of Hamburg

<sup>6</sup> In cases where there was more than one way, we chose the route with the shortest distance possible

<p><b>Port of Departure</b></p> <p>Country  <input type="text" value="Argentina"/></p> <p>Port  <input type="text" value="Buenos Aires"/></p> <p>Vessel speed, knots:  <input type="text" value="18"/></p>	<p><b>Port of Arrival</b></p> <p>Country  <input type="text" value="Germany"/></p> <p>Port  <input type="text" value="Hamburg"/></p> <p style="text-align: center;"><b>Calculate</b></p>	<p><b>Result</b></p> <p><b>Direct way</b></p> <table border="1"> <tr><td>Distance</td><td>6594 nautical miles</td></tr> <tr><td>Vessel speed</td><td>18 knots</td></tr> <tr><td>time</td><td>15 days 06 hours</td></tr> </table>	Distance	6594 nautical miles	Vessel speed	18 knots	time	15 days 06 hours
Distance	6594 nautical miles							
Vessel speed	18 knots							
time	15 days 06 hours							

#### 4. Port of Melbourne to Port of Hamburg

<p><b>Port of Departure</b></p> <p>Country  <input type="text" value="Australia"/></p> <p>Port  <input type="text" value="Melbourne"/></p> <p>Vessel speed, knots:  <input type="text" value="18"/></p>	<p><b>Port of Arrival</b></p> <p>Country  <input type="text" value="Germany"/></p> <p>Port  <input type="text" value="Hamburg"/></p> <p style="text-align: center;"><b>Calculate</b></p>	<p><b>Result</b></p> <p><b>Way #1</b></p> <table border="1"> <tr><td>Distance</td><td>11364 nautical miles VIA <b>Suez Canal</b></td></tr> <tr><td>Vessel speed</td><td>18 knots</td></tr> <tr><td>Time</td><td>26 days 07 hours</td></tr> </table> <p><b>Way #2</b></p> <table border="1"> <tr><td>Distance</td><td>12501 nautical miles VIA <b>Cape of Good Hope</b></td></tr> <tr><td>Vessel speed</td><td>18 knots</td></tr> <tr><td>Time</td><td>28 days 23 hours</td></tr> </table> <p><b>Way #3</b></p> <table border="1"> <tr><td>Distance</td><td>13009 nautical miles VIA <b>Panama Canal</b></td></tr> <tr><td>Vessel speed</td><td>18 knots</td></tr> <tr><td>Time</td><td>30 days 03 hours</td></tr> </table> <p><b>Way #4</b></p> <table border="1"> <tr><td>Distance</td><td>13550 nautical miles VIA <b>Strait of Magellan</b></td></tr> <tr><td>Vessel speed</td><td>18 knots</td></tr> <tr><td>Time</td><td>31 days 09 hours</td></tr> </table> <p><b>Way #5</b></p> <table border="1"> <tr><td>Distance</td><td>13614 nautical miles VIA <b>Cape Horn</b></td></tr> <tr><td>Vessel speed</td><td>18 knots</td></tr> <tr><td>Time</td><td>31 days 12 hours</td></tr> </table>	Distance	11364 nautical miles VIA <b>Suez Canal</b>	Vessel speed	18 knots	Time	26 days 07 hours	Distance	12501 nautical miles VIA <b>Cape of Good Hope</b>	Vessel speed	18 knots	Time	28 days 23 hours	Distance	13009 nautical miles VIA <b>Panama Canal</b>	Vessel speed	18 knots	Time	30 days 03 hours	Distance	13550 nautical miles VIA <b>Strait of Magellan</b>	Vessel speed	18 knots	Time	31 days 09 hours	Distance	13614 nautical miles VIA <b>Cape Horn</b>	Vessel speed	18 knots	Time	31 days 12 hours
Distance	11364 nautical miles VIA <b>Suez Canal</b>																															
Vessel speed	18 knots																															
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Time	31 days 09 hours																															
Distance	13614 nautical miles VIA <b>Cape Horn</b>																															
Vessel speed	18 knots																															
Time	31 days 12 hours																															

#### 5. Port of Walvis Bay to Port of Hamburg

<p><b>Port of Departure</b></p> <p>Country  <input type="text" value="Namibia"/></p> <p>Port  <input type="text" value="Walvis Bay"/></p> <p>Vessel speed, knots:  <input type="text" value="18"/></p>	<p><b>Port of Arrival</b></p> <p>Country  <input type="text" value="Germany"/></p> <p>Port  <input type="text" value="Hamburg"/></p> <p style="text-align: center;"><b>Calculate</b></p>	<p><b>Result</b></p> <p><b>Direct way</b></p> <table border="1"> <tr><td>Distance</td><td>5798 nautical miles</td></tr> <tr><td>Vessel speed</td><td>18 knots</td></tr> <tr><td>time</td><td>13 days 10 hours</td></tr> </table>	Distance	5798 nautical miles	Vessel speed	18 knots	time	13 days 10 hours
Distance	5798 nautical miles							
Vessel speed	18 knots							
time	13 days 10 hours							

## 6. Port of Shanghai to Port of Hamburg

<b>Port of Departure</b>		<b>Port of Arrival</b>		<b>Result</b>	
Country		Country			
<input type="text" value="China"/>		<input type="text" value="Germany"/>			
Port		Port			
<input type="text" value="Shanghai"/>		<input type="text" value="Hamburg"/>			
Vessel speed, knots:		<input type="button" value="Calculate"/>			
<input type="text" value="18"/>					

<b>Way #1</b>	
Distance	10778 nautical miles VIA <b>Suez Canal</b>
Vessel speed	18 knots
Time	24 days 23 hours
<b>Way #2</b>	
Distance	13664 nautical miles VIA <b>Panama Canal</b>
Vessel speed	18 knots
Time	31 days 15 hours
<b>Way #3</b>	
Distance	14096 nautical miles VIA <b>Cape of Good Hope</b>
Vessel speed	18 knots
Time	32 days 15 hours
<b>Way #4</b>	
Distance	17437 nautical miles VIA <b>Strait of Magellan</b>
Vessel speed	18 knots
Time	40 days 09 hours
<b>Way #5</b>	
Distance	17499 nautical miles VIA <b>Cape Horn</b>
Vessel speed	18 knots
Time	40 days 12 hours

## 7. Port of Lisbon to Port of Hamburg

<b>Port of Departure</b>		<b>Port of Arrival</b>		<b>Result</b>	
Country		Country			
<input type="text" value="Portugal"/>		<input type="text" value="Germany"/>			
Port		Port			
<input type="text" value="Lisbon"/>		<input type="text" value="Hamburg"/>			
Vessel speed, knots:		<input type="button" value="Calculate"/>			
<input type="text" value="18"/>					

<b>Direct way</b>	
Distance	1339 nautical miles
Vessel speed	18 knots
time	3 days 02 hours

## Appendix B: Advantages of Ports in Lithium Supply Chain

Supplier	Port	Advantages
Germany	Port of Hamburg	<ul style="list-style-type: none"> <li>- Well-developed infrastructure specialized for handling hazardous materials, crucial for the safe transportation of lithium compounds.</li> <li>- Efficient customs procedures ensure timely clearance for imported lithium shipments.</li> </ul>
Democratic Republic of the Congo (DRC)	Port of Matadi	<ul style="list-style-type: none"> <li>- Proximity to the DRC's lithium mining sites minimizes transportation lead times and costs.</li> <li>- Direct sea access facilitates the export of lithium ores and compounds to global markets.</li> </ul>
Chile	Port of Valparaiso	<ul style="list-style-type: none"> <li>- Located near major lithium mining regions in Chile, reducing transportation distances and costs.</li> <li>- State-of-the-art facilities enable the handling of large volumes of lithium exports efficiently.</li> </ul>
Argentina	Porto of Buenos Aires	<ul style="list-style-type: none"> <li>- Strategic location for shipping lithium products to international markets, including Europe and North America.</li> <li>- Well-established shipping routes ensure reliable and cost-effective transportation of lithium cargoes.</li> </ul>
Australia	Port of Melbourne	<ul style="list-style-type: none"> <li>- Proximity to lithium mining sites in Western Australia streamlines the</li> </ul>

		<p>transportation process, minimizing lead times.</p> <ul style="list-style-type: none"> <li>- Modern port facilities equipped to handle bulk shipments of lithium ores and concentrates.</li> </ul>
China	Port of Shanghai	<ul style="list-style-type: none"> <li>- Extensive shipping connections and advanced logistics infrastructure provide access to global markets for lithium exports.</li> <li>- Strategic location offers opportunities for integrating lithium supply chains with manufacturing hubs in China.</li> </ul>
Namibia	Port of Walvis Bay	<ul style="list-style-type: none"> <li>- Well-developed port infrastructure and deep-water berths accommodate large vessels carrying lithium cargoes.</li> <li>- Strategic position for shipping lithium products to European and American markets, contributing to supply chain diversification.</li> </ul>
Portugal	Port of Lisbon	<ul style="list-style-type: none"> <li>- Strategically located, providing easy access to major European markets such as Germany.</li> <li>- Portugal's favorable regulatory environment, including streamlined customs procedures and supportive government policies, fosters a conducive business environment for international trade and commerce.</li> </ul>

## Appendix C: Lithium Mining in North Central Portugal

# LITHIUM IN PORTUGAL

Lithium mining in the municipalities of the Northern and Central regions of Portugal:  
Areas requested, attributed, and foreseen for exploration or extraction between 2016 and 2021.

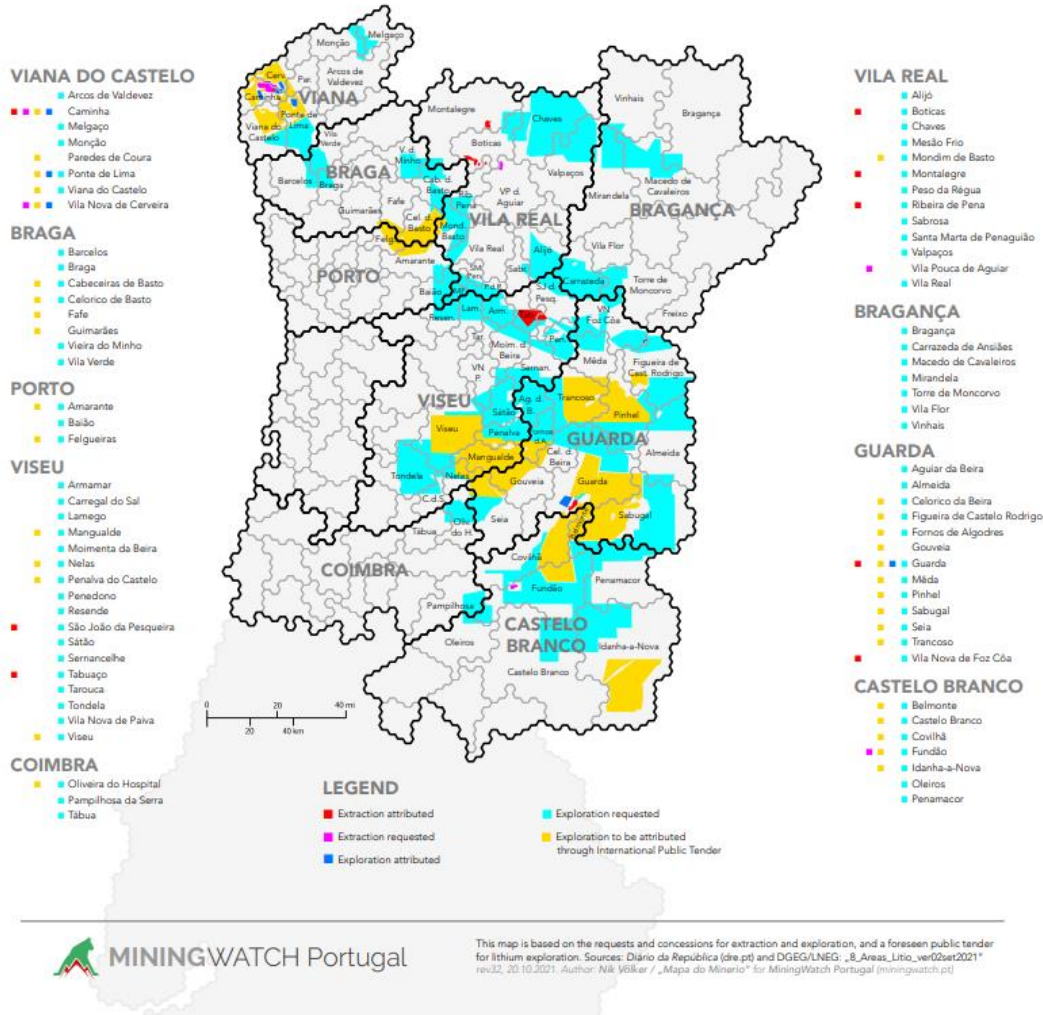


Figure 8 - Lithium in Portugal, Source: [https://miningwatch.pt/assets/pdf/Lithium\\_Mining\\_in\\_Northern\\_Central\\_Portugal-Municipalities-Districts-rev32-2021-En.pdf](https://miningwatch.pt/assets/pdf/Lithium_Mining_in_Northern_Central_Portugal-Municipalities-Districts-rev32-2021-En.pdf)