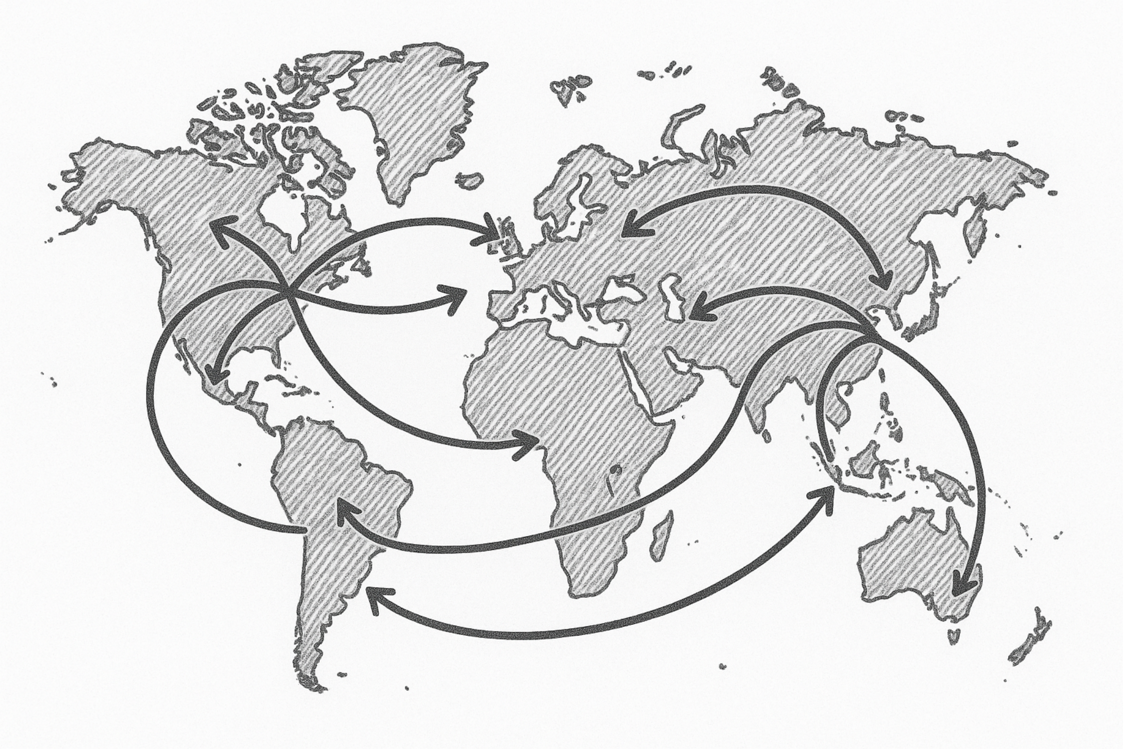

# Dependence Dynamics in the Upstream of Semiconductor Supply Chain to the Automotive;

## A case study with four embedded cases

Master's Thesis in Management and Economics of Innovation & Industrial Ecology

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Gothenburg, Sweden 2025
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# Interdependencies and dependencies in the upstream of semiconductor supply chain to the automotive

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Cover: A world map showing arrows and connections between countries similar to a supply chain structure.

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# Abstract

The increasing geopolitical uncertainty and prior disruption consequences have put pressure on automotive companies to increase visibility and control further upstream in the automotive semiconductor supply chain. This master thesis, initiated by an automotive OEM (the reference company), investigated the supply chains for four raw materials used in semiconductors; gallium, germanium, antimony and high-purity quartz. The focus was on mapping core actors, geographical locations for extraction, and understanding the dependencies and potential risks with these materials.

The method was based on a case study approach with four embedded cases, with each material being one case. Data was collected through extensive desk research, including market reports, annual reports and peer reviewed academic literature, and two rounds of semi-structured interviews with supply chain actors, experts and internal employees at the reference company. The findings show a highly concentrated supply network for some parts of the chain, especially in China, who dominates the refining capacity across three of the materials. Additionally, the findings reveals multi-level dependencies across the supply chain. Organizational (micro-level), inter-organizational (meso-level) and systemic (macro-level) each contribute to supply risks in the value chain.

With the use of resource dependency theory, power sources and multi-tier supply chain management, the study highlights that despite the eye-opener from COVID, companies still lack visibility beyond Tier 1 suppliers and strategies to reduce supply risks. The study found that reactive measures were more common than proactive ones across several tiers of the supply chain. Through mapping and analyzing dependence dynamics, this thesis aimed to provide insights and wake up calls for automotive OEMs and other actors across the supply chain, to prevent future disruptions to stall a whole supply chain. The semiconductor supply network should aim to be more resilient, and the findings underscore the need for greater visibility and transparency to reduce dependencies and supply risks.

# Sammanfattning (Swedish Abstract)

Den ökande geopolitiska osäkerheten och konsekvenserna av tidigare störningar har lett till att bilindustrin behöver öka insynen och kontrollen längre upp i halvledarleverantörskedjan. Denna masteruppsats, initierad av ett bilföretag (referensföretaget), undersökte leverantörskedjorna för fyra råmaterial som används vid tillverkning av halvledare: gallium, germanium, antimon och högren kvarts. Kartläggning av centrala aktörer, geografiska platser för utvinning samt att analysera beroenden och potentiella risker kopplade till dessa material var av huvudsakligt fokus.

Metoden som använts bygger på en fallstudie med fyra inneslutna delstudier, där varje material utgör ett eget fall. Datainsamling skedde dels genom omfattande reserach av tillgänglig information på internet så som marknadsrapporter, årsrapporter och vetenskapliga artiklar, samt två omgångar semistrukturerade intervjuer med relevanta aktörer, experter och interna medarbetare på referensföretaget. Resultaten visar att delar av leverantörsnätverket är starkt koncentrerat, särskilt i Kina, vilka dominerar raffineringen för tre av materialen. Dessutom visar resultaten att leverantörskedjan präglas av beroenden på flera nivåer: internt organisatorisk (mikronivå), organisationer emellan (mesonivå) och systemnivå (makronivå), vilka alla bidrar till potentiella risker i värdekedjan.

Genom att använda resursberoendeteorin (Resource Dependency Theory), identifiera källor till makt samt dela upp leverantörskedjor i systemnivåer visar studien att: trots lärdomar från COVID-19 pandemin saknar många företag fortfarande insyn bortom Tier 1-leverantörer samt strategier för att hantera risker. Studien visar också att reaktiva åtgärder är vanligare än proaktiva för många företag. Genom att kartlägga och analysera beroendedynamiker syftar denna uppsats till att ge värdefulla insikter och ge ett uppvaknande till bilföretag och andra aktörer i leverantörskedjan att vidta åtgärder, för att förebygga framtida störningar som kan påverka hela industrin. Leverantörsnätverket för halvledare behöver bli mer motståndskraftigt, och resultaten i denna studie understryker vikten av ökad insyn och transparens för att minska beroenden och leveransrisker.

Keywords: semiconductors, supply chain mapping, dependencies, resource dependency theory, supply risks, automotive industry, geopolitics

# Acknowledgements

This master's thesis was conducted at Chalmers University of Technology, Department of Technology Management and Economics, during the spring of 2025, in collaboration with an automotive company. We are deeply thankful to both institutions for providing the opportunity to carry out this project.

Our supervisor, Ala, has been a constant source of support throughout the entire process. With her valuable insights and expertise, she has guided us through the challenges we faced along the way. Even beyond the thesis, Ala has enriched our experience by arranging study visits and connecting us with industry professionals, from whom we have learned a lot. We are truly grateful for all the support and learning we've received from her.

We would also like to express our thanks to the focal firm for their continuous support. Their help in connecting us with relevant stakeholders and providing the opportunity to explore this topic through their perspective has been invaluable. In particular, we are grateful to our supervisor, co-supervisors, and all individuals who have supported us by hosting meetings, connecting us with relevant actors and offering their guidance throughout the project. We are deeply grateful for the trust you have shown in our success throughout this journey.

Lastly, we would like to take this opportunity to thank all external stakeholders and participants in this study. Your willingness to share your perspectives and engage in open discussions has deepened the analysis and provided invaluable first-hand insights. Your contribution has been essential to the success of this research, and we truly appreciate your time and input.

Thank you!

**Moa Lennström, Gothenburg, May 2025**

**Filip Andersson, Gothenburg, May 2025**

# List of Acronyms

Below is the list of acronyms that have been used throughout this thesis listed in alphabetical order:

| | |
|---|---|
| CRM Act | Critical Raw Materials Act |
| CPU | Central Processing Unit |
| GaAs | Gallium Arsenide |
| GaN | Gallium Nitride |
| HPQ | High-Purity Quartz |
| IDM | Integrated Device Manufacturer |
| MCU | Micro Controller Unit |
| MSCM | Multi-Tier Supply Chain Management |
| OEM | Original Equipment Manufacturer |
| OSAT | Outsourced Assembly and Test |
| RDT | Resource Dependency Theory |
| SCM | Supply Chain Management |
| SMC | Semiconductor |
| SRM | Supply Risk Management |
| TSMC | Taiwan Semiconductor Manufacturing Company |

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# 1

# Introduction

This chapter will present an introduction into the topic. It starts with the background, followed by the problem statement, purpose and delimitations of the project.

## 1.1 Background

The automotive industry relies heavily on semiconductors, which are vital components that manage various functions in modern vehicles ranging from engine operation to safety features and infotainment systems. As vehicles transition toward greater automation, electrification, and connectivity, the demand for semiconductors are growing.

However, this growing dependence together with tensions across the globe exposes significant risks and vulnerabilities on the supply side. The COVID-19 pandemic served as an eye-opening reminder of how fragile supply networks can be. When manufacturing plants shut down and transportation was disrupted, semiconductor production slowed dramatically. Meanwhile, a surge in demand for consumer electronics during lockdowns intensified competition for limited chip supply. For the majority of firms in the automotive sector, this led to delays in vehicle production and deliveries and an increased awareness of the complex dependence dynamics in the supply chain. This supply shortage of semiconductors shocked the market and forced companies to put efforts in supply chain resilience management (Mohammad et al., 2022). One of the most complex supply chains in the world, the semiconductor supply chain, was now put up on the map.

In addition to disruption events like a pandemic, further complications arises from geopolitical tensions, particularly between China, USA and Taiwan. Some are highly relevant today between China and USA with active export restrictions (McCarthy, 2025). Export controls and trade restrictions introduce new risks of supply disruptions. Hence, the strategic importance of securing resilient and sustainable supply chains is becoming more and more important for companies both inside and on the periphery of the semiconductor industry. The regional tensions between Taiwan and China regarding Taiwan's autonomy remain a critical geopolitical concern (Bukhari et al., 2024). However, this raises a broader question: Are there additional potential risks emerging from underlying dependency dynamics that we today are not aware of? Several steps in the semiconductor supply chain are highly concentrated in a few key countries, many of which are entangled in geopolitical conflicts. This poses a threat to the stability and resilience of global supply chains for essential components.

When producing semiconductors, a number of raw materials are needed. Four of them are gallium, germanium, high-purity quartz and antimony. These are of extra interest due to geopolitical and capacity concerns. Gallium, germanium and antimony are already part of the list of critical raw materials by the European Union (European Commission, 2020). Logically, the demand for these raw materials will increase together with the growing market for semiconductors. Three of the named materials are highly concentrated materials, extracted and produced in Asia and especially China. High-purity quartz, unlike the other materials mentioned, is more widely available and can be found in more locations.

However, the understanding of key players, extraction locations, and the dynamics of dependence within the upstream supply chain is generally limited. End customers often struggle with a lack of transparency and visibility. To ensure long-term stability and prepare for future disruptions, a deeper understanding of the upstream supply chain is valuable. Without adequate transparency, downstream companies, such as automotive OEMs, face challenges in assessing and managing the associated risks.

### 1.1.1 Resource Dependency in Semiconductors

Being in control over essential resources required for an activity to occur is equal to power in Resource Dependency Theory (Pfeffer & Salancik, 1978). Since the semiconductor supply chain is highly complex with more than 70 international border crossings (Alam et al., 2020), different power structures are highly present. Resource Dependency Theory outlines four key power positions: independence, buyer power, supplier power, and interdependence (Hillman et al., 2009).

While tangible dependencies such as access to raw materials, manufacturing equipment, infrastructure and logistics are more apparent, less visible but equally critical factors also shape the distribution of power. Geopolitical tensions, resource concentration, trade relations and shifts in market demand are some examples of dependencies that have a big impact on power positions in the semiconductor supply chain. In the context of supplying semiconductors to end-users and ensuring a stable supply, the most common type of power structure today is supplier power. Automotive companies are heavily dependent on their suppliers, largely due to limited visibility into the upstream supply chain. In such a low-transparency environment, trust alone may not be enough to ensure a stable supply. To regain control and reduce vulnerability, companies must actively find ways to challenge the existing power positions.

### 1.1.2 Mapping the Specific Supply Chain

According to Garcia et al. (2024), there is a need for more studies to map the supply network for automotive Semiconductor and Electronic Components. The authors highlights the importance of having knowledge about the internal and external environments in the network, which can be done by investigating the influence of regulatory, technological, and supply-related uncertainties. Together with this, OEMs require increased resources and technical knowledge to effectively manage regulatory, technological, and supply uncertainties (Garcia et al., 2024). These resource and knowledge requirements are expected to be identified through a thorough mapping of the supply chain.

To further be able to challenge existing power positions, a clear understanding of the current landscape and situation is essential. Since power positions and dependencies are shaped by a range of factors embedded in the various stages of the supply chain, it is essential to do a mapping of the specific supply chain. Identifying power positions and dependencies requires a thorough understanding of the supply chain's structure and network. Key elements such as locations of natural resources, mines, key industry players, the geographic distribution of critical operations, market shares, trade relationships, and geopolitical influences must all be analyzed to highlight dependencies and potential strategic leverage points. Firstly after the current landscape and situation is displayed, the power positions and dependencies can be identified.

The Critical Raw Materials Act (CRM Act) is an initiative by The European Commission to ensure a stable supply of critical raw materials to Europe (European Commission, 2024). The regulation aims to strengthen the value chains of critical raw materials for EU, by mapping where raw materials are produced and how to secure a stable supply through strategic projects. Germanium, gallium and antimony are part of the list (European Commission, 2020), and gallium and germanium are part of strategic projects in the Act (European Commission, 2025). As seen in Figure 1.1, China holds a majority of the chosen critical raw materials, including antimony, gallium and germanium.

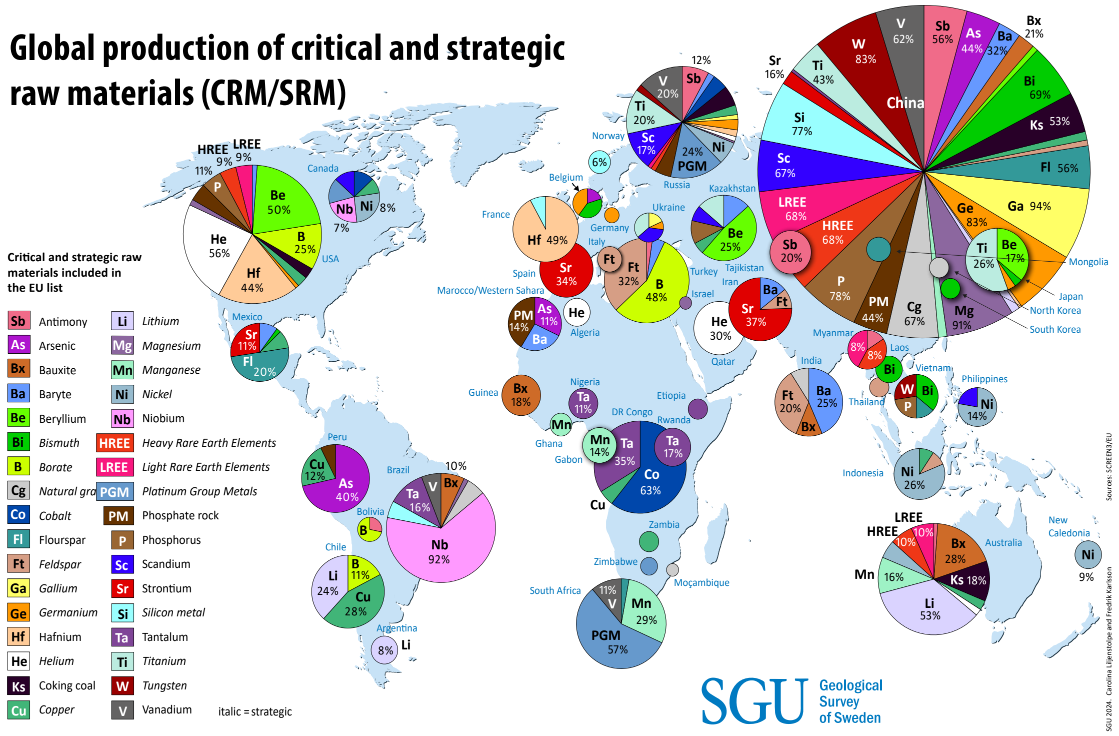


**Figure 1.1:** Global production of critical and strategic raw materials by the European Commission, borrowed from (Geological Survey of Sweden, 2024)

## 1.2 Raw materials and Usage in Semiconducting Components

The four raw materials in focus are essential for the production of semiconductor components. The semiconductor industry relies on these materials, among others, for a stable and functioning supply chain to secure the demand. These minerals are essential for chip functionality and performance, but they are often sourced from a limited number of countries. With rising geopolitical tensions and increasing attention to disruptions and risks, it's essential to understand where these materials originate and how supply disruptions might occur. Some of the materials are sourced together with other materials, so called byproducts. When separated, the materials goes through different grades of purification which are separate processes sometimes done by different companies. To be able to map the supply network with relevant locations and actors, it is important to firstly understand what processes is needed, both in terms of extraction and refinement. Further, the usage and applications of the materials in components is also essential to be able to determine where the materials end up. When this is done, a complete mapping with both locations and actors can be put in to place.

### 1.2.1 High-Purity Quartz

High-purity quartz is the raw material used in the production of silicon wafers for high-tech applications, such as microchips. A common misconception is that silica sand is used for these applications, but silica sand contains a lower purity level. Sourcing materials of the highest purity is a fundamental requirement in the semiconductor supply chain, and high-purity quartz is therefore specifically extracted and processed for its exceptional purity. This high level of purity significantly simplifies the refining process, making it the preferred choice for higher technology applications.

High-purity quartz undergoes a number of processing steps to extract silicon, which is then formed into ingots and sliced into wafers. This is separate activities, done by different companies. Due to a long history of research and technical advantages, the absolutely dominant element for microchips is silicon, where dopants are added to achieve new functionality. It is an extremely innovative technology based on physics, technology, and the ability to manufacture these components on the nanoscale. Therefore, high-purity quartz is essential for producing semiconducting components.

### 1.2.2 Gallium

Gallium is an important material for the production of high-technology semiconductors. It is used as a dopant for silicon wafers, but also for Gallium Arsenide (GaAs) and Gallium Nitride (GaN) wafers. Jaskula (2021) mention that 95% of the gallium was produced from bauxite during alumina production as a byproduct, while the rest was sourced from refining lead and zinc ores.

Gallium is typically available in different purity levels, most commonly referred to as low-grade (technical-grade) and high-grade (electronic-grade) gallium, depending on the intended application. To obtain high-grade you need to refine the low-grade primary material (Jaskula, 2021). In 2021, it was estimated that China accounted for 97% of worldwide low-grade primary production. However, Canada, China, Japan and USA refined high-grade gallium from low-grade primary material in 2021 (Jaskula, 2021). Hence, it is evident that China has an upper hand in the gallium market due to the need of low-grade gallium.

### 1.2.3 Antimony

Antimony is a metal that is not found in pure form. It is a byproduct of other metals, particularly gold. It is partly known for being a material used for doping silicon for microelectronics, but is mainly used in infra red vision. However, some semiconducting contains antimony and it's therefore relevant. The trade of antimony is under pressure, especially between China and USA. In December 2024, China banned all exports of antimony to the USA (Lv & Munroe, 2024). Since China holds a large share of the global market the tensions poses a risk towards eventual disruptions. Antimony is extracted mainly in three countries; China, Tajikiztan and Russia (Klochko, 2025). In total, 17 countries are mining antimony but China controls 60% of the market Klochko (2025). Refineries are also highly concentrated in China, holding an even greater market share of 79% (Klochko, 2017).

Additionally there is a rising demand of resourced used in the military and defence sector, which puts Antimony in the center of attention. The future outlook shows that China will continue to hold their market position as the leading antimony supplier, since it has the availability and capabilities of the antimony refining and processing infrastructure (Perpetua Resources, 2021).

### 1.2.4 Germanium

Germanium plays a vital role in advanced technologies mostly of its infrared transparency and optical performance. It has chemical similarities to silicon, and is a critical raw material according to The European Comission (European Commission, 2020; Scrreen, 2023b). Germanium can also be used as a dopant for certain silicon-based semiconductors, mostly for high-speed applications such as radio frequency chips and more advanced processors.

Since germanium is too reactive to be found naturally, the material is extracted together with other substances (Scrreen, 2023b). The extraction and processing of germanium are complex due to its dispersed nature in various ores rather than existing as primary minerals (Torma & Jiang, 1991). The most common substances that Ge are sourced from are sulfide ores of zinc and coal deposits (Ruiz et al., 2018), but not all ores bear germanium in a concentration worth to extract. Regarding refineries, China has a close to monopoly with 94% market share (Tolcin, 2025).

## 1.3 Problem statement

Despite the strategic importance of semiconductors and the growing attention paid to downstream manufacturing and supply, the upstream supply chain remains poorly understood. There is a lack of detailed mapping and transparency of the supply chains for critical and strategic raw materials that are used in these components. Additionally, there is generally a low understanding of the key actors and dependencies related to the critical raw materials.

This limited visibility comes with challenges for both companies and other actors that is affected by the industry. Without clear insights into the origins, actors and processes of these materials, it is difficult to assess exposure to potential supply disruptions that can follow from geopolitical tensions, market shifts, misalignments and general uncertainties. The highly concentrated market of production and refining in some regions further amplifies the risks and dependencies.

This thesis focuses on the supply chain mapping and market analysis of four selected raw materials that are relevant for SMC manufacturing. These are high-purity quartz, gallium, antimony and germanium. These materials were selected based on their strategic importance and current relevance in discussions about securing future semiconductor supply chains. Through an in-depth investigation of the upstream supply chain structure and dependence dynamics, the study aims to contribute knowledge and shed a light on a poorly understood part of the supply chain. The study hopes to motivate companies to investigate in potential upstream supply risks, and enable actors in the industry and others to make informed decisions.

## 1.4 Purpose and Research Questions

The purpose of this project is to investigate the upstream supply chains of four raw materials used in semiconductors, with a focus on identifying key dependence dynamics and risks. By highlighting the structure and dynamics of these supply chains, the study aims to support more informed decision-making and motivate actors to investigate and be aware of dependencies in the supply chain. Through a global supply chain mapping with a focus on high-purity quartz, gallium, antimony and germanium, the research identifies dependence dynamics, bottlenecks, and potential supply risks. Hence, the following research questions will be answered;

*RQ1: What does the supply chain look like for gallium, germanium, antimony and high-purity quartz including core actors and geographic locations?*

*RQ2: What dependence dynamics exist and how do they contribute to potential risks in the supply chain for the four raw materials?*

## 1.5 Delimitations

The research adopts the perspective of a Northern European automotive OEM and the semiconductor usage in the automotive sector. Broader industry applications of semiconductors are acknowledged but not explored in depth. In addition, the analysis draws from public data, market research, and expert interviews. Some supply chain activities and mapping are hard to trace due to confidentiality, data unavailability, or proprietary practices. The focus is on the upstream part of the supply chain, with particular focus on high-purity quartz, gallium, germanium and antimony. Although there are other critical raw materials relevant for the semiconductor industry, they are not considered in the study due to the time constraints.

The study pursues in an environment where confidentiality is high. Hence, some data will be confidential and therefore converted into anonymous data or in some cases left out completely. This may lead to some findings being generic or neglected.

## 1.6 Outline of the thesis

The structure of the thesis is arranged as in Table 1.1.

| **Chapter** | **Content** |
|---|---|
| 1. Introduction | Outlines the background, research problem, purpose, research questions, and scope of the thesis. It also includes characteristics of the four embedded case raw materials. |
| 2. Theoretical Frame of Reference | Presents the theories used in the study, including Resource Dependency Theory, supply risk management, and the semiconductor supply chain characteristics. It also shows the framework used for later. |
| 3. Methodology | Describes the research design and the phases, data collection methods, interview strategy and analysis process |
| 4. Empirical Context | Describes the current situation of the reference company regarding what is missing and known, as well as empirical background of the raw materials. |
| 5. Empirical Findings | Describes the supply chain mapping findings and the dependencies at the micro, meso, and macro levels, explaining how they seem to contribute to supply risks in the upstream supply chain. |
| 6. Discussion | Interprets findings in light of the theoretical framework, focusing on visibility gaps, power imbalances, risk mitigation strategies. It discusses the findings from the different levels and also discusses the supply chain mapping findings. |
| 7. Conclusion | Summarizes the main findings, answers the research questions, and reflects on managerial implications and limitations of the study. |

**Table 1.1:** Thesis Structure Overview

# 2

# Theoretical Frame of Reference

In this chapter, the theoretical framework will be presented. It begins with resource dependency theory and sources of power, followed by ways to manage risks through dependencies, and ends with the supply chain of semiconductors.

## 2.1 Managing Interdependencies and Dependencies In The Supply Chain

Modern supply chains are not linear but tend to be increasingly complex and interconnected networks where firms are more or less dependent on one another for resources, capabilities, knowledge and so forth. The interdependencies and dependencies that exists in these supply chain, where the semiconductor is a prime example, create both opportunities and risks. Disruptions in one part can severely impact across other parts, similar to what we saw during the pandemic in 2020.

This section outlines key theoretical concepts related to dependencies in supply chains. The first part introduces Resource Dependency Theory as a base for analyzing and understanding organizational relationships and dependencies. The second part explores how power and dependence exists within supply networks, and the third part discusses how interdependencies can be managed through risk mitigation.

### 2.1.1 Resource Dependency Theory

Resource Dependency Theory (RDT) suggests that power is held by the actor who controls the essential resources required for an activity to occur (Pfeffer & Salancik, 1978). Dependency and power is two closely related words and it is stated that the one side that are less dependent on the other side, hence possess more power over that side (Pfeffer & Salancik, 1978). In a supply network, actors possess different power positions towards each other, and Emerson (1962) highlight that according to RDT the actors level of dependence can be changed by altering them. There exists four power positions in RDT; independence, buyer power/dominance, supplier power/dominance and interdependence. Independence means that there exists no dependency between the actors or parties. According to Caniëls and Gelderman (2005), buyer power arises when the supplier is more dependent on the buyer than the buyer is on the supplier. Conversely, supplier power is present when the buyer relies more heavily on the supplier than the supplier does on the buyer. However, interdependence means that both parties have mutual dependence on each other (Casciaro & Piskorski, 2005).

Organizations must sometimes engage in transactions with external actors and suppliers to access the resources they need. When both the concentration and uncertainty of resources are high, suppliers and producers can become mutually dependent over time (Celtekligil, 2020). Mutual dependence can make a collaboration stronger, while a power imbalance between actors can have the opposite effect (Casciaro & Piskorski, 2005). Organizations need to adapt their business strategies to the dependencies which can be by diversification of suppliers, increased scale of production and developing new links to other actors (Archibald, n.d.). RDT is a framework for understanding how companies monitor their dependencies on external actors to ensure stability, independency and efficiency in their supply.

According to Straub et al. (2008), organizations must limit their external dependencies when relying on resources that are critical, and RDT helps managing those dependencies. Environmental uncertainty is connected to the sourcing of critical resources, which can lead to difficulties and uncertainties due to limited availability and accessibility (Celtekligil, 2020). To handle this, organizations can initiate new inter-organizational relationships. According to Celtekligil (2020) diversification of supplier or dependency management can be used by organizations to decrease their dependencies on single suppliers. Archibald (n.d.) states that links to other organizations must increase together with an increased uncertainty. By doing this, organizations are spreading risks and ensuring a more stable supply chain by securing their supply through a variety of actors.

### 2.1.2 Power and Dependence In The Supply Chain

Pfeffer (1981) means that power sources exists in different levels. Either in network-, relationship- or organization level. In supply networks, power depends both on how the network is structured and on the role each actor plays within it. By looking at the relationships between different organizations, it becomes possible to understand how much influence one actor has over another. This influence is shaped by several factors, such as who controls important information, how strong their negotiation and bargain skills are, how much experience they have, what kind of product is being exchanged, how hard it is to switch partners, how large the business volume is, and how long the relationship has lasted. At the organizational level, the power depends more on the uniqueness, expertise, size, brand etc. Pfeffer (1981) mean that power can be assessed by examining an organization's internal capabilities and resources, rather than solely through its relationships with other actors. This view is closely connected to the power of reputation as discussed by Pazirandeh and Norrman (2014). The way Pfeffer (1981) views power in terms of network, relationship and organization is related and addressed in Pazirandeh and Norrman (2014) as well, however instead in power sources from substitutability, demand share, interconnection, information asymmetry and reputation. Pazirandeh and Norrman

(2014) suggest that assessing the current status of these categories allows organizations to actively manage key indicators in order to strengthen or reduce power imbalances.

Considering some of the power sources discussed by Pazirandeh and Norrman (2014) in the context of the semiconductor industry, some are highly relevant in terms of managing supply chains. Substitutability means the ease of replacing one supplier with another. As indicated multiple times, the semiconductor supply chain is highly complex and in some sectors along the value chain, only a few possess the right competence and expertise to complete certain steps. Thus, there is low substitutability, or high market concentration rather than high substitutability at certain tiers. This perspective considers both the number of available suppliers in the market and the entry barriers that may prevent new suppliers from entering. Due to high investment costs to manufacture chips, entry barriers are high and hence substitutability is low.

Information asymmetry refers to the unequal distribution of information between actors in a relationship and reflects the level of transparency within the interaction (Pazirandeh & Norrman, 2014). Indicators concerns for instance demand awareness, knowledge of the supply market and position in the flow of communication. In order to mitigate supply risks, it was previously discussed about the importance of mapping the supply chain. Information asymmetry shows that the actor is not well aware of its surroundings. Hence, low asymmetry is desired. Peters (2024) mean that having long-term relationships with suppliers could possibly reduce the asymmetry as better relationships enhance information sharing.

Reputation refers to company size, brand identity, legitimacy and the resources the company possesses (Pazirandeh & Norrman, 2014). Having high reputation means being a reliable customer with a good external image. However, having a good reputation does not necessarily mean having high power. For some end customers that use semiconductors in their products, their size toward the whole industry is very small. Hence there are not necessarily interdependency. There will be no change if the industry loses some end customers, but there will be big change if the customer loses its supply.

### 2.1.3 Managing Supply Risks Through Dependencies and Interdependencies

Recent events that have occurred have showed organizations what real impact it may inflict on the business continuity. The semiconductor crisis of 2020-2023 is one example, which led to a global disruption for many industries. The consequences of such events have led to raised awareness and attention to supply chain risk management and constructing a resilient supply chain (Mohammed et al., 2023). The semiconductor crisis of 2020–2023 exposed how deeply firms in the automotive sector depend on upstream suppliers and invisible nodes further along the supply chain. This has led to growing awareness that supply risk is closely tied to a company's ability to identify, understand, and manage these dependencies.

One important way of addressing these risks is through conducting proper supply chain mapping, particularly at multiple tiers (Peters, 2024). Mapping not only helps firms identify key suppliers but also uncovers hidden dependencies, such as when multiple Tier 1 suppliers rely on a shared Tier 2 or Tier 3 actor. As Peters (2024) highlight, multi-tier mapping enables quicker, more informed decisions that can prevent or mitigate risks and disruptions. There are numerous other studies made on how to manage risks within supply chains. For instance, Blos et al. (2009) who investigated electronic and automotive companies in their case study, highlighted how most of the firms pointed towards better supply chain communication, better risk management and training programs.

Interdependencies and dependencies also influence the effectiveness of traditional risk management strategies. Peters (2024) mentions that one key factor that intensified supply chain disruptions during the COVID-19 pandemic was the widespread reliance on just-in-time (JIT) manufacturing, which minimized inventory levels to reduce costs and increase efficiency. However, this approach left many firms unprepared and as a result there has been growing interest in transitioning toward a "just-in-case" inventory strategy , which emphasizes maintaining larger safety stocks to buffer against supply disruptions (Peters, 2024). Even though it may enhance resilience, it also comes with other challenges. Peters (2024) highlight that having buffer stocks might hinder a firms' flexibility and thus limit their ability to adopt new technologies. Having sunk costs and investments in old technology just in case of a disruption can quickly result in obsolete inventory. Matsuo (2015) add context to this, stating that adding inventories are only suitable if it sustains a competitive advantage. Instead of buffering, Matsuo (2015) raises the idea of supply chain virtual dualization. This is to improve supply chain flexibility by making design information more portable across different manufacturing sites or suppliers. This strategy focuses on flexibility rather than redundancy, allowing firms to adapt more quickly when disruptions occur (Matsuo, 2015). In this way, managing dependencies through design, supplier relationships, and information flows becomes a form of proactive risk management.

Kleindorfer and Saad (2005) categorize supply chain risks as either coordination-related or disruption-related. This thesis focuses on the latter, particularly disruptions that arise when upstream dependencies are not well understood or managed. There are three main tasks of disruption risk management identified by Kleindorfer and Saad (2005). These are specifying the sources of risk and vulnerability, risk assessment, and risk mitigation. Matsuo (2015) explain the risk management as a process of identifying, assessing, mitigating, and responding to risks. Managing these disruptions effectively requires specifying sources of vulnerability, assessing exposure, and building mitigation and contingency capabilities, all of which are enhanced by increasing visibility into interdependent actors across the supply network.

Recent studies emphasize the necessity of integrating interdependency modeling into supply chain risk management processes. This integration enables firms to capture how risks and mitigation strategies interact across the supply network, improving risk assessment accuracy and the effectiveness of mitigation plans (Qazi et al., 2017; Vicente, 2024). While many studies addressing risk interdependencies focus on linear, process-based supply chain flows, such an approach is often insufficient for capturing the complexity of modern supply chain networks, where relationships are multi-tiered, dynamic, and non-linear (Qazi et al., 2017). Vicente (2024) states that the best practices for managing interdependent risks include supply chain visibility and transparency across tiers. Hence will risks and vulnerabilities be better understood. This is closely tied to collaborative risk planning, which the includes engaging suppliers in joint risk assessment and shared responsibility for managing interdependencies (Vicente, 2024). Thus, risks, dependencies and interdependencies are closely connected terms. Managing supply chain risks effectively today requires a shift from isolated risk management to a holistic approach that explicitly addresses dependencies within the supply network.

### 2.1.4 Multi-tier Supply Chain Management

Many of today's supply chains are long and complex and involve many different actors, industries and contexts and due to this length, the knowledge and visibility of the included suppliers in the value chain fades with the number of tiers (Sauer & Seuring, 2019). In the context of raw material suppliers, i.e. the tier-n suppliers, the visibility is often out of reach for the focal firm. For this purpose, the theory of multi-tier supply chain management (MSCM) becomes relevant, as it aims to reach deeper down in the supply chains, as described by (Mena et al., 2013).

There are different forms MCSM where the simplest form is a three-tier (triad) system comprised of a buyer-supplier-supplier network (Mena et al., 2013). This structural arrangement means that companies, often the buyer, have extended the network beyond the first tier, to instead go in direct contact with the second tier, and thus aim to manage the supply network as a competitive resource (Mena et al., 2013). The purpose is to reach a higher state of stability and reduce supply risks, as it requires simultaneous cooperation and competition among actors.

Multi-tier supply chains are beneficial for several reasons. Mohammed et al. (2023) brings up sustainability and resilience as two of many. The authors mean that due to the dynamic business landscape today and the interconnections and dependencies between supply chain networks, sustainability and resilience are the key to ensure business continuity. Moreover, to have efficient collaboration between all parts. A multi-tier supplier network strategy is one start, as it goes beyond the first tier supplier and directly establishes contact with second or even lower tier suppliers (Mena et al., 2013). Additionally, the point of a multi-tier strategy is to also increase visibility and transparency. In the report by Deloitte (2021), it was highlighted that prioritizing critical value streams and drilling into multi-tier connections is necessary but also resource-intensive. It takes a lot of time and it is never certain that a true picture will emerge out of the effort.

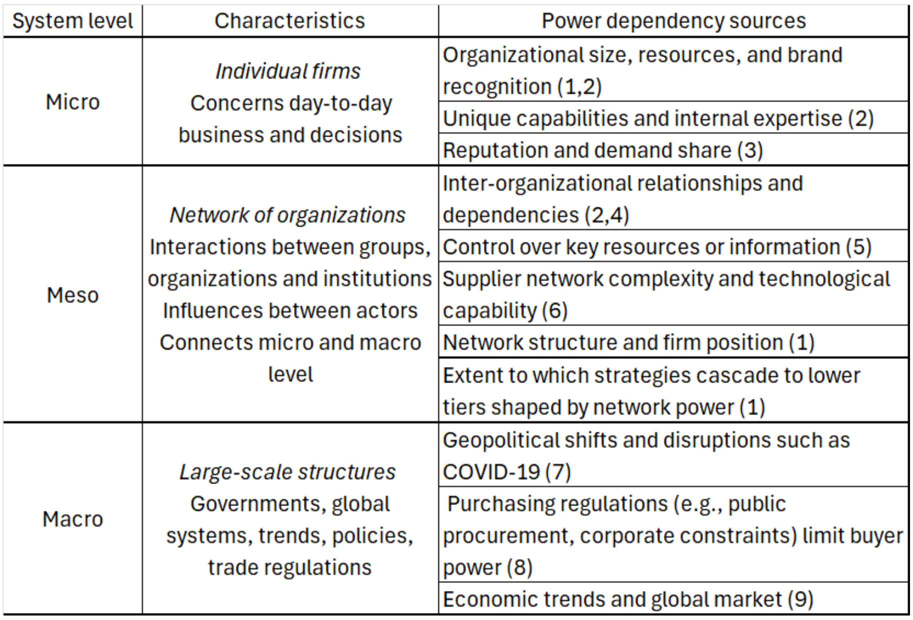
### 2.1.5 A Need For a Broader System Perspective

The following conceptual framework seen in Figure 2.1 illustrates the distribution of power and dependency across three levels of the semiconductor supply chain.

At the micro system level, which covers the individual firm and its day-to-day business and decisions, organizational size, knowledge and expertise influence power dynamics. Firms with substantial resources, strong brand recognition, and unique capabilities tend to have greater influence within the supply network (A.-K. Kähkönen et al., 2015; Pfeffer & Salancik, 2003). According to Pazirandeh and Norrman (2014), reputation and demand share also influences the power dynamics.

The meso system level covers the network of suppliers and the power dynamics in it, where relationships between firms and the dependencies are important factors (Caniëls & Gelderman, 2005; Pfeffer & Salancik, 2003). According to Pfeffer (1981) controlling critical information can have an impact on power dynamics, where resource control can lead to power. Beyond the previously mentioned factors, buyers also rely on suppliers with extensive, complex networks and strong technological capabilities (Xiao et al., 2019). Sources of power are influenced by firms and their structure of network, and according to A. K. Kähkönen et al. (2023) they also influence how far strategies can extend to lower-tier suppliers.

Considering the macro perspective, McNamara and Newman (2020) argue that geopolitical factors and global disruptions, like the market changes following the Covid-19 pandemic, play a key role in reshaping power dynamics. Pazirandeh and Herlin (2014) suggest that purchasing regulations, such as public procurement rules and corporate strategy constraints, can reduce the influence of buyers, ultimately affecting their power within a network. Since power relations are dynamic, larger changes in the global market and shifts in economic trends can have an impact on the dynamics (Cox, 2004).



| System level | Characteristics | Power dependency sources |
|---|---|---|
| Micro | *Individual firms*<br>Concerns day-to-day business and decisions | Organizational size, resources, and brand recognition (1,2) |
| | | Unique capabilities and internal expertise (2) |
| | | Reputation and demand share (3) |
| Meso | *Network of organizations*<br>Interactions between groups, organizations and institutions<br>Influences between actors<br>Connects micro and macro level | Inter-organizational relationships and dependencies (2,4) |
| | | Control over key resources or information (5) |
| | | Supplier network complexity and technological capability (6) |
| | | Network structure and firm position (1) |
| | | Extent to which strategies cascade to lower tiers shaped by network power (1) |
| Macro | *Large-scale structures*<br>Governments, global systems, trends, policies, trade regulations | Geopolitical shifts and disruptions such as COVID-19 (7) |
| | | Purchasing regulations (e.g., public procurement, corporate constraints) limit buyer power (8) |
| | | Economic trends and global market (9) |

**Figure 2.1:** Author's table over power dependence sources in different system levels. Source: 1 (A.-K. Kähkönen et al., 2015); 2(Pfeffer & Salancik, 2003); 3(Pazirandeh & Herlin, 2014); 4(Caniëls & Gelderman, 2005); 5(Pfeffer, 1981); 6(Xiao et al., 2019); 7(McNamara & Newman, 2020); 8(Pazirandeh & Norrman, 2014); 9(Cox, 2004)

## 2.2 Supply Chain of Semiconductors

The semiconductor supply chain is highly complex, with more than 1,000 production steps and over 70 international border crossings before a component reaches the final customer (Alam et al., 2020). This global complexity makes the entire system vulnerable to disruption, as a policy change or an event affecting even a single firm or step can lead to far-reaching consequences and significant costs. As an example, the rapid development of China's semiconductor sector may alter existing supply chain structures, posing challenges to global security and the competitive standing of established industry players (Khan et al., 2021).

The supply chain of semiconductors involves multiple activities, ranging from R&D to distribution and sales. Each step contributes to value creation, and are important for the supply chain to function seamlessly. Semiconductor manufacturing typically follows three core stages: design, fabrication, and assembly, testing, and packaging (ATP). In some cases, a single company, known as an integrated device manufacturer (IDM), carries out all these steps and markets the final chip. In other cases, the process is divided among specialized firms. Fabless companies handle the design and sales, while they rely on foundries for chip fabrication and on outsourced semiconductor assembly and test (OSAT) providers for assembly, testing, and packaging (ATP) services. The production of semiconductor components depends on a range of inputs, including materials, semiconductor manufacturing equipment (SME), electronic design automation (EDA) tools, and core intellectual property (IP). Since these inputs are usually supplied by different specialized firms, the supply chain becomes highly complex (Khan et al., 2021). The flow and process can be seen in Figure 2.2. Adding another layer on to the semiconductor supply chain, the upstream supply chain starting from the supply of minerals and raw materials is also highly complex which are the backbone of a complete supply chain. Young (2018) highlights this complexity of the mineral supply chain very well. It is described that previous efforts made by electronic manufacturers to trace the metals used in their product chain did not work out. The chains could easily involve up to nine facilities in different locations. Additionally, Young (2018) also mentions that the involvement of different chemical and physical transformations at refineries and smelter further prevent the traceability of metal units.

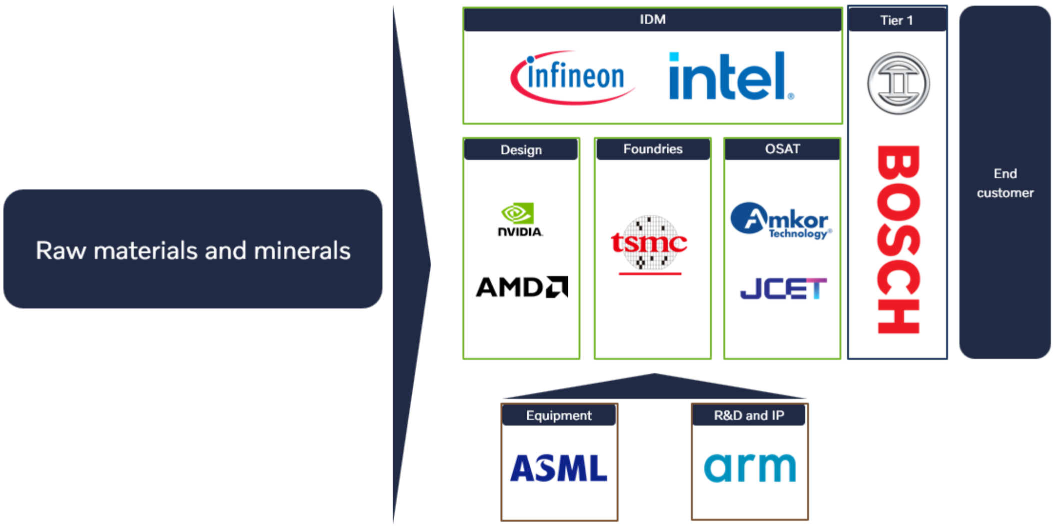


**Figure 2.2:** Author's illustration over the steps of the semiconductor supply chain in a simplified figure, including one or two of the major firms in each category

There are a lot of electronics in vehicles today. It is estimated that by 2030, electronics will represent 45% of a car's manufacturing cost. Thus, automotive OEMs are becoming more reliant on the supply of electronics. However, the relationships that these companies have today are not fully established, therefore lacking visibility downstream and relying more on Tier 1 suppliers. King et al. (2021) mentions how previous disruptions at semiconductor firms have led to greater supply chain disruptions and semiconductor shortages for other companies. It comes from dependencies on a few major firms that are crucial for the semiconductor industry to function properly. Asia's leading chip manufacturers, TSMC and Samsung, currently lack the capacity to fully meet the growing demand for semiconductor components, leading to production bottlenecks. TSMC almost hold a monopoly on certain components, and together with Samsung they produce 92% of all advanced chips globally (Dorakh, 2024). Furthermore, companies such as Nvidia and AMD are designing chips but rely on a limited number of highly advanced foundries for manufacturing. Most of this contract chip production is concentrated in Asia, particularly in Taiwan and

South Korea, home to TSMC and Samsung. According to King et al. (2021), this concentration and limited capacity represent major bottlenecks in the global semiconductor supply chain. It also demonstrates the complexity and dependencies that exist throughout the value chain.

### 2.2.1 Strategic cooperations in the semiconductor sector

Dorakh (2024) highlight that EU lacks the manufacturing capabilities to produce integrated circuits. Since the 2000s, a horizontal segmentation started to separate design firms from contract foundries. Firms in Europe and UAA primarily focused on being IDMs which resulted in the lack of capabilities in the west. Thus, the advanced chip manufacturers became located in Asian countries. Taiwan especially invested a lot in advanced manufacturing, helping TSMC become the world's top producer of high-tech chips. Because of this, Europe became more dependent on Asian suppliers, and between 2016 and 2022, EU imports of semiconductor products grew by about 132% (Dorakh, 2024). Due to the heavy investments necessary to develop capabilities and produce chips, Dorakh (2024) means that cooperation is necessary to now reshape the industrial landscape.

As of 2023, new partnerships between automotive and chip manufacturers are being developed. A key example is the establishment of the European Semiconductor Manufacturing Company (ESMC) in Dresden, Germany. This joint venture marks a strategic collaboration between major players such as TSMC who owns 70% of the venture, and European firms Infineon, NXP, and Bosch (Dorakh, 2024). With this new initiative, the aim is to become less dependent on Asia and have a closer manufacturing to serve the European market better. By establishing local production facilities and collaborating across borders, these firms aim to improve supply security and reduce dependency on single regions. This initiative aligns with Xiong et al. (2024) who states that investing in domestic production is crucial to keep up with the pace of the technological demands and changing landscape for semiconductors. The authors also highlight the importance of policy initiatives and government incentives to support these kind of transitions. However, Xiong et al. (2024) means that talent shortages is one key challenge that might slow down the transition.

### 2.2.2 Lack of Visibility in the Upstream Semiconductor Supply Chain

Historically, automotive firms have relied heavily on their Tier 1 suppliers for a full system integration (Garcia et al., 2024), leading to no direct relationships to companies closer to the direct semiconductor suppliers. Due to this trust and overreliance on direct suppliers, it has not been necessary to be aware of the supply network. Only now, when technological advancements and supply uncertainty after a global crisis become evident, automotive OEMs are trying to change this approach. Garcia et al. (2024) mean that companies now establish connections across the supply network instead and imply that OEMs should not rely on direct suppliers anymore. King et al. (2021) moreover indicate how the global supply shortage from COVID revealed the lack of knowledge that OEMs possessed about semiconductors, and also the lack of relationships. Furthermore, as Alam et al. (2020) highlights, the supply chain of semiconductors might cross more than 70 nations and 1000 production steps, thus making the network very large and difficult to grasp. The further upstream one looks in to the supply chain, the less traceable it becomes. One of the core reasons is particularly this, the complexity. The automotive semiconductor supply chain is referred to as diamond-shaped, making it nearly impossible to fully map or know all upstream suppliers, and many OEMs only achieve 10-20% visibility beyond their immediate suppliers today (Deloitte, 2021).

Also Bowen and Siegler (2024) mention other companies in other industries and their general reliance on Tier 1 suppliers. While firms may believe they have diversified their supply base by working with numerous Tier 1 suppliers, this perspective can be misleading. In reality, supply chains are part of much larger, layered networks where dependencies may exist further upstream (Bowen & Siegler, 2024). For example, a major computer assembler based in USA, during the supply disruptions of early 2020, discovered that despite having dozens of different Tier 1 suppliers, most of them were ultimately connected to the same small group of Tier 2 and 3 suppliers. Crucially, these upstream suppliers were all concentrated in a single geographic area, Wuhan, China. This became a bottleneck when the region was affected by COVID-19 lockdowns (Bowen & Siegler, 2024). The same principle applies for semiconductor companies and the whole industry. In one way or another, every company is dependent on either a company, region or country in order to get their products. In the case for semiconductors, actors are dependent on China for critical raw materials and TSMC for chip manufacturing. However, due to the complexity of the semiconductor supply chain, visibility decreases further upstream. This case highlights the limitations of focusing only on Tier 1, and also Tier 2, visibility and shows how hidden dependencies further down the supply chain can create systemic vulnerabilities, especially when key components or raw materials are sourced from geographically concentrated areas.

The lack of upstream transparency is often reinforced by outsourcing and trust-based delegation, where suppliers are expected to manage their own supply chains without disclosing detailed information (Cho et al., 2017). In the semiconductor industry where intellectual property protection and competitive secrecy are high, suppliers may also be reluctant to share upstream data. This further limits the ability of downstream firms to gain a full picture of their supply chain and network. Due to the vast majority of firms in the industry and only indications of who could be included in the supply chain of an automotive semiconductor, it will be almost impossible to know for sure which companies have supplied parts or components to a specific semiconductor.

# 3

# Methodology

This chapter presents the methodology of the project and the process. It includes the methods that are useful and necessary to collect data and answer the research questions. The chapter begins with describing the research design and the four embedded case studies followed by the three phases that were used as a pathway for the research.

## 3.1 Research Design and Case Studies

The context for this study is grounded in the automotive sector, where the demand for semiconductors continues to grow rapidly. However, the focus of the study is not an automotive OEM itself, but the upstream supply chain structure, dependence dynamics, and risks associated with the four materials high-purity quartz, gallium, antimony and germanium. Thus, this study applies a multiple case study design focused on four mentioned raw materials which are critical for semiconductor manufacturing. With this case design, each raw material represents a case in itself with the aim of analyzing its upstream supply chain and network, its degree of visibility, and the dependence dynamics that exist for and within each system level, as well as its relevance to the automotive sector. Hence a reference company, a global automotive OEM, is present in the study. By treating each material separately as four embedded cases, a more nuanced understanding of risks and dependencies can be achieved.

The reason for the selection of these four different raw materials comes from purposeful sampling. Internal knowledge and priorities from the reference company helped to identify the four raw materials. The motivation laid mostly in their high relevance to product performance, exposure to geopolitical and supply risks, and its lack of knowledge of origins in terms of extraction and processing. Thus, the reference company opened up internal doors to relevant departments involved in sustainability, purchasing and risk- and crisis management. Sustainability departments were relevant since workers in this field can experience challenges regarding visibility and transparency in supply chains in order to get relevant information, which is relevant for this thesis.

The process of a case study is described by Yin (2018) and consists of different phases as plan, design, prepare, collect, analyze and share. The methodology process for this research was adapted from this to suit the needs of the study with slight modifications. This research is thus split into three different phases, starting from planning and reaching until finalization. A visualization of the process and phases can be seen in Figure 3.1. Phase one will focus more on collecting information internally within the focal firm, while phase two will be a combination of both internal and external communication, including contact with suppliers. Each phase will be described in further detail in the coming sections.

The benefit of using a case study approach is to enable a combined usage of different qualitative methods (Knights & McCabe, 1997). Thus, over reliance of one single method is avoided. Although different case study approaches often can be blurred together, such as intrinsic, instrumental and collective case studies, this case study will be one more of an instrumental nature. This is mainly since the case is meant to gain knowledge for involved parties on a broader issue (Bell et al., 2022). Throughout the process, continuous engagement and communication between the researchers, the university and the reference company ensured alignment, feedback, and iterative validation of the research direction.

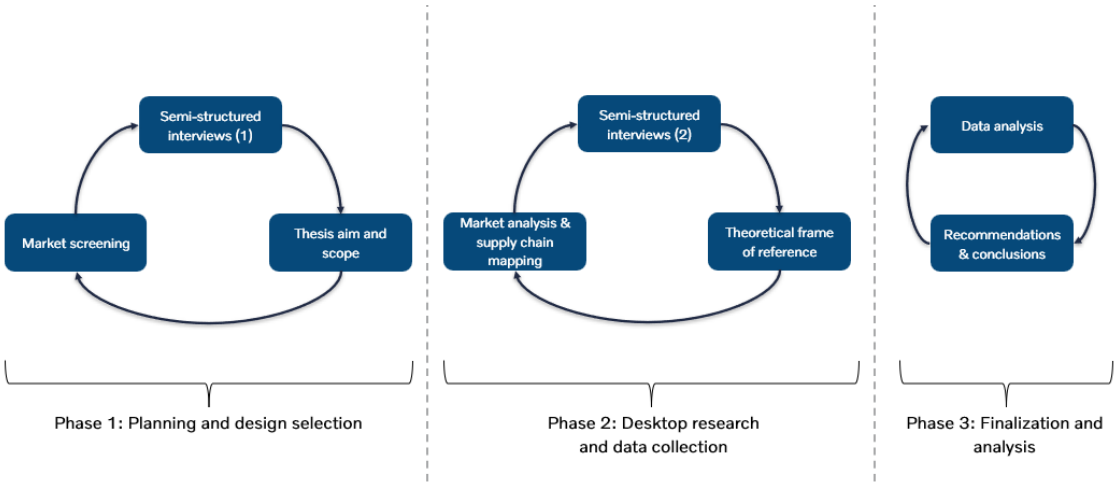


**Figure 3.1:** Author's figure showing the method approach of the research and the phases

## 3.2 Phase 1: Planning and design selection

Yin (2018) emphasizes the importance of narrowing and clearly defining the area of study. This was addressed during the initial phase of the methodology, where discussions about the company's assigned project helped establish the scope and objective of the thesis. This process was done in parallel with a market screening and semi-structured interviews to investigate and specify the topic. The following sections will aim at explaining those sub-phases.

### 3.2.1 Market screening

In the beginning of the study a market screening was conducted. The aim was to grasp and understand the value chain of semiconductors and its complexity, together with getting a hint of extraction locations and key players. Additionally, it also helped in understanding the size of the scope better and thus allowed the researchers to better estimate the time and effort needed to conduct the goal of the research. The market screening included public sources and documents of information from previous market analysis and company reports. In addition, internal documents from the focal firm were also studied to see their current understanding. This was done more in deep in upcoming phases as well, but then turned more into a deep analysis of the topic, as will be described later in this chapter.

As Bell et al. (2022) mentions, data archives from for instance governments are generally trustworthy sources, and often free of charge for researchers. These data archives was of great use to collect relevant data and numbers for some type of information. As the environment the scope lays in is shifting fast, the market screening was carried out throughout the project to stay up to date. Thus, the initial research and the deep dive overlapped with this method, continued in phase two as well.

### 3.2.2 Semi-structured interviews

In the initial phase of the research, the scope and objective is usually blurry and not static, thus this first phase was focused on collecting relevant data and information to build upon. Hence, semi-structured interviews were conducted as part of the first stage in the case study. This method is suitable for case studies and allows researchers to keep an open mind about what they need to understand, allowing concepts and theories to be formed from the data (Bell et al., 2022). It also allows for asking additional questions as the interviewer might pick up on things said by interviewees (Bell et al., 2022).

The semi-structured interviews were conducted with employees from relevant departments inside the focal firm to gain a better overview of the current situation and to find both the known and unknown about the topic in question. With the help of convenience sampling methods, such as snowballing and purposive sampling, it ensured that the most relevant individuals were contacted and interviewed. The sampling was conducted together with the supervisor in the focal company. From these initial interviews, it was made possible to extend the range to other relevant stakeholders who could provide other perspectives on the matter. During the interviews, a rather thorough interview guide was used to better grasp the topics, but the aim was to leave the floor open for a more generalized discussion as well. Additionally, the aim was also to bring forward the desires of the organization to enable the researchers to narrow down the scope even further. A table showing the interviews can be seen in 3.1. The interview guide can be found in Appendix A.

| Interview | Respondent | Role | Department | Length (min) | Date | Company |
|---|---|---|---|---|---|---|
| 1 | Sirius | Manager | Technology | 60 | 2025-02-10 | Reference company |
| 2 | Rigel | Purchaser | Purchasing | 40 | 2025-02-12 | Reference company |
| 3 | Vega | Consultant | Risk & Crisis | 60 | 2025-02-13 | Reference company |
| 4 | Altair | Consultant | Risk & Crisis | 60 | 2025-02-13 | Reference company |
| 5 | Deneb | Leader | Sustainability | 60 | 2025-02-13 | Reference company |
| 6 | Procyon | Leader | Sustainability | 60 | 2025-02-17 | Reference company |
| 7 | Antares | Analyst | Strategy | 60 | 2025-02-18 | Reference company |
| 8 | Capella | Manager | Technology | 60 | 2025-02-19 | Reference company |
| 9 | Pollux | Leader | Sustainability | 60 | 2025-02-19 | Reference company |

**Table 3.1:** Overview of interviews conducted in the first round

In each interview, different topics became the focus depending on the respondent. The topics discussed in each first round interview can be seen in Table 3.2. As seen, the focus became more focused on the current state of knowledge and how the situation was seen in today's business landscape, focusing more on, for instance, visibility and risks.

| Respondent | Topics Discussed |
|---|---|
| Sirius | Current situation and scope alignment |
| Rigel | OEM visibility; risks; raw material origins |
| Vega | OEM visibility; risk and crisis management routines; current knowledge of materials; early warning systems |
| Altair | OEM visibility; risk and crisis management routines; current knowledge of materials; early warning systems |
| Deneb | Environmental concerns; impact of extraction |
| Procyon | Environmental concerns; impact of extraction |
| Antares | Geopolitical risks; OEM visibility; current state of topic knowledge |
| Capella | OEM visibility; supply chain resilience strategies; risk mitigation |
| Pollux | Environmental concerns; impact of extraction |

**Table 3.2:** Topics discussed in the first round

### 3.2.3 Thesis aim and scope

During the first phase, the thesis aim and scope were discussed, reviewed and modified. The market screening and interviews made it possible to increase the understanding of the topic and to find interesting gaps in terms of understanding and known information. The initial thought of the research was to include both a mapping, environmental impact assessment and a geopolitical risk assessment. However, this broad topic was continuously refined and specified by the discussions and screening, which finally resulted in the establishment of the two research questions for this study and a narrowed scope, leaving a few initial goals out of the scope. The researched realized that to be able to conduct a environmental assessment, the supply chain must be understood before. Therefore, the mapping of resources and actors were set to be the first step, followed by analyzing dependence dynamics and potential risks that were exposed from the mappings.

## 3.3 Phase 2: Desktop research and data collection

In the second phase of the research, another round of semi-structured interviews were carried out with both internal and external actors. Additionally, a deep dive into the market was conducted with the aim of mapping the supply chain as accurate as possible. This was made to validate the findings from the desktop research with the help of interviewing key actors in the industry. When findings were validated, the mapping was updated. The process of conducting phase two of the research can be seen below in Figure 3.2.

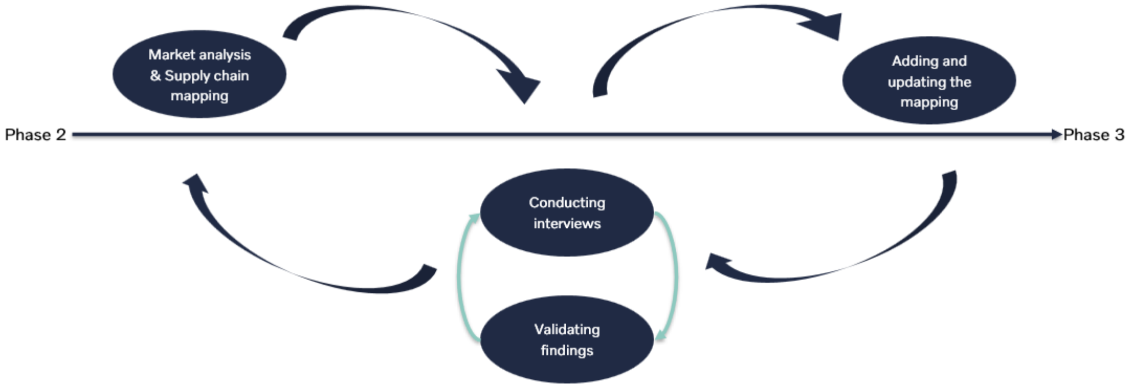


**Figure 3.2:** Author's illustration of the process of phase two in the research

### 3.3.1 Market analysis & Supply chain mapping

The market analysis and supply chain mapping were conducted through an iterative and exploratory process, aimed to build a comprehensive understanding of the external context and also validate the findings. As illustrated in the beginning of this section in Figure 3.2, the process followed a loop of conducting interviews, performing market research, and continuously validating the findings.

Initially, market research was performed to gain an overview of the industry landscape which included current trends, key actors, and geopolitical and other challenges in the supply chain. This involved reviewing industry reports, academic literature, news articles, company disclosures and annual reports. As described in the next section, interviews were also of big help in conducting the market analysis. As the research progressed, a preliminary supply chain mapping was developed based on publicly available data and company-specific information from the data collection. The mapping highlighted key actors of the chain, particularly those related to extraction of the relevant raw materials and their geographic locations. Since the supply chain of semiconductors are one of the worlds most complex value chains, the mapping was made carefully to be as accurate as possible. The accuracy was difficult to completely verify, but interviewees along the way was used to do verifications of the findings. Nevertheless, the mapping was made with the thought of shedding a light on the need of taking action and proactive measures in order to be aware of future potential risks, and give a hint of where they likely would occur. Therefore, the mapping did not have to be totally accurate and perfect, since the purpose was to give a somehow understanding of the situation.

#### 3.3.1.1 Documents

In addition, different documents from the focal firm were read with the aim of providing more background information (Bell et al., 2022). This gave a hint of where information was lacking and where gaps could be filled with this research, relevant for both the focal firm and the broader public.

Additionally, other organizational documents from other firms and suppliers were read with the aim to collect data from company statements relevant particularly in the context of geopolitics. The aim of these documents is to gather information of prior events and find the lessons learned, but also gave a broader view of where the focus has been previously. Organizational documents can provide information about company regulations, policy statements, etc. as stated by Bell et al. (2022), but annual reports are also powerful documents to be used for this purpose. Especially important were the annual reports to find the operational statements from firms, and certain outputs and capacities of mines and refineries. Also, it could reveal different connections between players. These documents served as a powerful way to backtracking the supply chain to in the end collect the necessary data on the extraction of raw material from the relevant key players. However, as Bell et al. (2022) highlights, to overcome the credibility obstacles of these types of reports, it may be useful to also look at alternative documentary sources. Hence the idea to combine several different types of documents.

#### 3.3.1.2 Academic literature

Simultaneously as the interviews were conducted, academic literature and research articles were read. This was done both to gather relevant theory and to ask better and more relevant interview questions. Additionally, literature served as a way to collect more knowledge about the topics, both at the component and raw materials level but also regarding geopolitics and prior disruption events. Moreover, it acted as a method to find and collect quantitative data on the four raw materials that could be used to map them better. For instance, percentage data on production, mining and reserves or data on environmental impact.

The literature search was conducted with the help of Google Scholar and Chalmers' own data bases where scientific papers and reports were read. Several keywords were used to find useful articles, and the snowball technique was used to find additional articles. Snowballing is a structured method of looking at the references or citations, or both, of already relevant papers to find additional literature or places for gathering data (Wohlin, 2014).

### 3.3.2 Semi-structured interviews

In parallel with the market analysis and supply chain mapping, a second round of semi-structured interviews were conducted. The interviews held at this later stage in the process were designed to continue on interesting topics mentioned in the earlier stages of interviews, together with new relevant findings from the desktop research. Additionally, one aim was to continuously validate and verify our findings with experts in the industry to allow for an ongoing process in the right direction. If some findings were not seen to be mutually correct by the interviewee and the researcher, an open discussion occurred. This was indeed the aim in order to understand both sides perspectives and come to a better conclusion. The interviewees were both internal employees at the focal firm as well as external actors in the industry. It could be tier 1 or 2 suppliers, experts, or even companies closer to the start of the upstream supply chain, which would have more insight and visualization of the value chain relevant for the scope.

For this round, some questions were prepared and tailored to fit the corresponding interviewee, together with a few general questions asked to all interviewees. To ensure all prepared questions were covered and to maintain high data quality, both thesis authors participated in all interviews. The interview findings often prompted new questions or highlighted areas requiring deeper investigation through further market research. A combination of in-person interviews at the company's office and remote interviews was conducted. Table 3.3 presents the full list of interviews. Notes were taken during each session, and if possible and if allowed by the interviewee, all interviews were recorded. In some cases, interviewees did not feel comfortable being recorded, which was mostly the case when sensitive information was touched upon. The recordings were later transcribed to facilitate subsequent data analysis. To find the interview guide for the second round, see Appendix A.2.

During a few interviews, questions were asked to be sent out in advance to a few interviewees. During one or two of these interviews, it became evident that interviewees made efforts to search for information in beforehand, which led to the believe that interviewees did not respond according to their actual knowledge, but rather according to information available on the internet. Since the market analysis gave a deep understanding of available data sources, some information given from interviewees were taken directly from some of these sources. Therefore, it was considered later on not to be beneficial to send out questions in advance since this did not show what interviewees actually knew about the topics.

| Interview | Respondent | Role | Department | Length (min) | Date | Company |
|---|---|---|---|---|---|---|
| 1 | Mercury | Mining Specialist | Purchasing | 60 | 2025-03-28 | Reference Company |
| 2 | Venus | Director | Sales | 60 | 2025-03-28 | Global silicon wafer manufacturer |
| 3 | Tellus | Professor in Microtechnology and Nanoscience | Research | 60 | 2025-04-01 | University |
| 4 | Mars | Geoscientist | Research | 60 | 2025-04-11 | University |
| 5 | Jupiter | Purchaser | Purchasing | 60 | 2025-04-14 | Global semiconductor manufacturer |
|  | Saturn | Purchaser | Purchasing | 60 | 2025-04-14 | Global semiconductor manufacturer |
| 6 | Uranus | Professor in Microtechnology and Nanoscience | Research | 60 | 2025-04-24 | University |
| 7 | Neptune | Purchaser | Purchasing | 60 | 2025-04-25 | Component supplier |
|  | Ceres | Purchaser | Purchasing | 60 | 2025-04-25 | Component supplier |
|  | Pluto | Purchaser | Purchasing | 60 | 2025-04-25 | Component supplier |
| 8 | Haumea | Professor in Microtechnology and Nanoscience | Research | 60 | 2025-05-08 | University |

**Table 3.3:** Overview of interviews conducted in the second round

Interview data was collected across different supply chain stages. The source of data included interviews with suppliers and expert insights from researchers and academia. Additionally, the desktop research was used both as a primary source of data as well as a complement to validate data. The overarching data covering the whole supply chain was done by market research from several sources. Figure 3.3 therefore illustrates the position of interviewees within the upstream semiconductor supply chain. The figure should be understood as a representation of supply chain actors based on the primary expertise of the interviewees. While interviewees represented various stages, such as the reference company, Tier 1 suppliers, wafer and ingot production, and IDMs, no representatives from the raw material extraction stage were available for interviews, as discussed in Section 3.3.3. Thus, although some interviewees had overlapping knowledge across stages, the placement in the figure reflects their main area of expertise where the respondents could provide us with the most input, insights and reflections, rather than strict organizational supply chain roles.

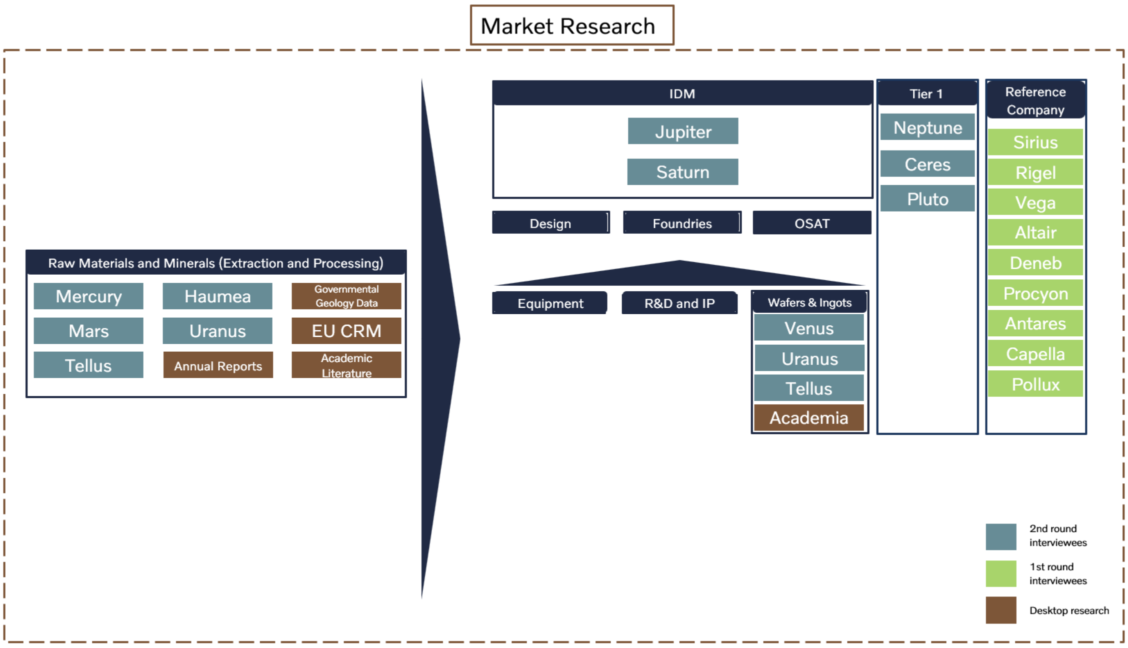


**Figure 3.3:** Author's illustration over the data collection across the upstream semiconductor supply chain. The figure illustrates which parts of the supply chain were informed by first round interviewees (green color), second round interviewees (blue color) and desk research (brown color)

To better visualize what the main topic and input was from each respondent, Table 3.4 was created. Depending on where in the supply chain each respondent was present, it became evident that different views and insights could be generated. Therefore each interview from time to time became tailored to generate discussions which would enlighten the findings on different levels, for instance from a micro-meso-macro perspective, or simply from a transparency or risk perspective.

Furthermore, all interviews followed an interview guide developed by the authors, as described earlier. However, as interviews progressed, the interview guide were modified in line with what the interviewees knowledge and input gave. Therefore, later interviews could have slightly different approaches in terms of questions and main topics, which was also based on where in the supply chain and which expertise the interviewee possessed.

| Respondent | Topics Discussed |
|---|---|
| Mercury | Mining locations and actors; raw material network and dependencies |
| Venus | Upstream suppliers; supply network dependencies |
| Tellus | Semiconductor technology; raw material dependencies |
| Mars | Network dependencies; supply risks; raw material locations |
| Jupiter | Supplier network dependencies; risk management |
| Saturn | Supplier network dependencies; risk management |
| Uranus | Semiconductor technology; network dependencies |
| Neptune | Network dependencies; risk management |
| Ceres | Network dependencies; risk management |
| Pluto | Network dependencies; risk management |
| Haumea | Semiconductor technology; raw material dependencies |

**Table 3.4:** Topics discussed in the second round

### 3.3.3 Access and outreach attempts

As part of the data collection process, outreach efforts were made to a wide range of companies and industry actors, particularly those involved in the upstream supply chain. These efforts included email invitations and contact through company websites. Despite repeated attempts, the majority of companies did not respond. This limited direct input from certain key supply chain actors that would have been highly important for the study and its validity. A majority of relevant companies found from the mapping was based in China. Due to this, an attempt was taken to go through an employee at the focal firm sitting in China, where language barriers could be reduced. Although this attempt, answers were still limited.

## 3.4 Phase 3: Finalization and analysis

In the third and last phase of the research, the empirical findings from the market analysis and semi-structured interviews were compiled and analyzed in order to come up with conclusions and recommendations. To be able to analyze the data properly, analytical tools where used to find patterns and contradictions among the interviewees and other data. The methods of the third phase can be read below.

### 3.4.1 Data analysis

The data analysis process was of a qualitative, exploratory and iterative nature, aligning with the exploratory nature of the research, rather than structured around traditional coding or statistical analysis. Nevertheless, from time to time, it was found beneficial to search for similarities and repetitions, similar to the method of pattern matching, as described by Yin (2018), which involves structuring the findings. The goal was to develop an accurate supply chain mapping and conduct a market analysis, which required the integration of both secondary data, i.e. desktop research, and primary data, i.e. interviews. An additional goal was to highlight the complexity of the supply chain and find patterns showing the limited visibility and knowledge, even for companies present in the value chains. Quotes were searched for in order to add understanding. As previously stated, interview data was used to validate and discuss findings from the initial market research. As new insights came from desktop research, which could be new identifications of key actors or unheard or unknown risks, these were brought into interviews for confirmation, clarification, or challenge. Thus, potential misunderstandings were allowed to be corrected or elaborated on. In most cases, the insights of the interviews were not treated as standalone data points but rather as complementary inputs that helped triangulate the findings.

Furthermore, to structure the analysis of dependencies and interdependencies in the upstream semiconductor supply chain, a multi-level perspective was applied by using the concepts of micro, meso and macro levels. This way of analyzing the data was used in order to organize and interpret the data and responses from interviewees regarding the various views of dependencies and power across the value chain. The aim was to structure the findings to support a more nuanced understanding of how and where the dependencies plays a role in the supply chain, as well as to see how broad each respondent thought of and was aware of the topic in their day-to-day business. Thus, splitting into three different levels therefore showed in what scale the views were seen. The framework of micro, meso and macro was used both during coding as well as in synthesizing the findings.

The micro level refers to the level of individual firms, such as those within the reference OEM with characteristics such as size, resources and reputation. The meso level refers to a broader industry-level perspective and its dynamics in a more inter-organizational manner. This view takes the network into consideration and has characteristics such as interactions between groups and organizations, control over resources and network structure. Lastly, macro refers to systemic and large-scale structures with characteristics such as geopolitical shifts and disruptions, purchasing regulations and economic trends.

As Bell et al. (2022) points out, the main difficulty in analyzing interviews is handling unstructured language in transcripts and notes, which results in a complex database. Hence, a straightforward pathway to analyze these data can be difficult to find. However, as Bell et al. (2022) further notes, this requires the researcher to not get stuck in the richness and mass of data. Rather than conducting formal coding, notes and transcripts were reviewed to extract meaningful themes and illustrative quotes that supported or clarified key parts of the analysis. Quotes were selected based on their relevance, clarity, and ability to exemplify core findings. Data from the data collection sources were then used to create an accurate visual mapping.

### 3.4.2 Recommendations and conclusions

The last step of the third phase involves coming up with recommendations and conclusions from the conducted research. This was made from the data analysis where clear gaps where spotted and where clear emerged findings could be found which would generate a deeper understanding of the topic, both for the focal firm and the broader research community.

## 3.5 Quality of research

Ensuring the research quality of a case study requires consideration of especially reliability and validity as highlighted by Bell et al. (2022), which in turn influence the credibility and trustworthiness of the study. Yin (2018) describes that reliability refers to the consistency and stability of the research process. If a researcher wants to conduct similar research with the same methodology, similar findings will be achieved. However, reliability is closely related to replicability and refers to what extent the research can be replicated by others (Bell et al., 2022). In order to stay reliable in research, a full transparency of the methodology can be displayed, which in turn improves the replicability. Thus, to enhance both reliability and replicability in this research, a structured documentation of data collection and analysis procedure was followed. The aim and goal was to minimize the researcher bias and improve transparency, as highlighted by Bell et al. (2022).

Validity on the other hand assesses whether the research accurately captures what it aims to study Yin (2018). Firstly, construct validity is ensured due to multiple use of data sources, i.e. data triangulation (Yin, 2018). Secondly, internal validity was ensured through the use of thematic coding and that themes aligned with theory (Eisenhardt, 1989). Lastly, external validity was also ensured, which refers to how well the findings can be generalized (Yin, 2018).

# 4

# Empirical Context

This chapter presents the empirical context of the study, offering an overview of the current challenges and risks in the semiconductor industry, and relevant supply chain dynamics. Understanding this context is essential to interpret the observed challenges and strategies related to supply chain mapping and actor dependencies.

## 4.1 Current Supply Chain Challenges and Risk Landscape

The semiconductor market is volatile and affected by fluctuations in demand, supply shortages, and geopolitical tensions. At the same time the market is highly concentrated for some activities. The vast majority of companies involved in the semiconductor supply chains across the world are crossing paths in one way or another with the Taiwanese global semiconductor manufacturer TSMC. Without TSMC, the world would be without supply of semiconductors and risk a shortage, similar to the one in 2020, caused by the Covid-19 pandemic (Capella, February 2025). However, as tensions arises between Taiwan and China today, it is a hot topic in the day-to-day business how to mitigate the impact of a potential disruption. Additionally, trade restrictions from China on key metals such as gallium, germanium and antimony, together with an increasing political instability across the globe adds another layer of uncertainty. Furthermore, the supply chain of minerals is complex and includes many tiers. Without a proper understanding of the included parts and suppliers, there is a potential threat of a ceased supply at some point. The case company wants to gain knowledge of the suppliers that are part of the supply chain in order to better understand the market and be prepared for disruptions, but also to hold leverage as part of their sustainability strategy.

While the company has a dedicated risk management team, its focus has traditionally been on immediate supply chain risks rather than raw material sourcing. To achieve a more comprehensive risk management approach, the company must extend its analysis to the early stages of the supply chain, particularly in mining and raw material extraction of metals crucial for semiconductor production, including antimony, gallium, germanium, and high purity quartz. These materials are currently majorly possessed by countries such as China, adding an additional layer of supply risk.

### 4.1.1 Flow of Raw Materials in Semiconducting Components

The flow and use of the four materials is illustrated in Figure 4.1 which was constructed with the help of the reference company, mainly with the help of interviewee Rigel and Antares from the first round interviews. The illustration gives a simple overview of how the process look like for the four raw materials and which steps are present. The aim of the picture is to only give a background context of the process and not a complete picture, since the process steps of manufacturing was not the main scope of the study. Therefore, germanium and antimony remain simply illustrated without any further steps until it reaches the silicon wafer.

The first step for high-purity quartz is purification into metallurgical grade, and after that into electrical grade which is also called polysilicon. The next step is Czochralski pulling, which is a method for creating single-crystals ingots, or boules. When the boule is formed, this can be sliced into thin wafers.

For gallium, the main point of use is in either becoming a gallium-arsenide (GaAs) or a gallium-nitride (GaN) wafer. In order to become that, it is retrieved from baxuite as a first step, then turned into low-grade gallium. From there, it needs further purification to become high-grade gallium. The process of becoming either sort of wafer, it goes through boule growth and epitaxial growth. GaAs wafers is more common to be used in high frequency applications rather than used in CPUs or memory storage, meanwhile GaN wafers are more common in power transistors.

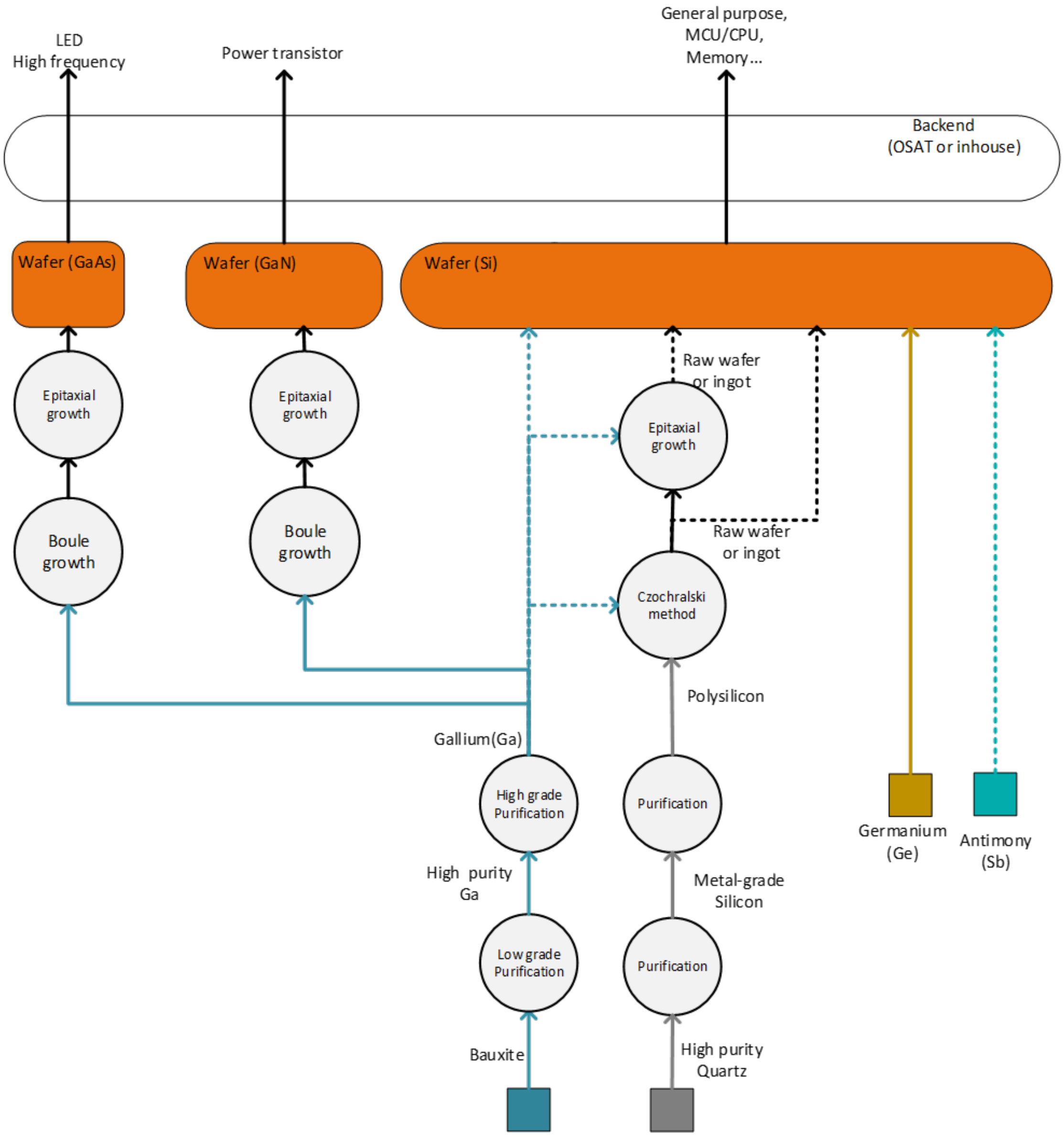


**Figure 4.1:** Flow of materials for semiconducting components. Source: reference company and own research

### 4.1.2 Overview of the 4 Case Raw Materials

**High-purity quartz** (HPQ) is used in the production of silicon wafers for semiconductors, especially in applications that require high chemical purity. It is also possible to instead of HPQ use highly purified original quartz, but the steps needed to obtain such high purity are many. The supply chain is limited, but not that concentrated in only one country, with only a few companies globally capable of producing the required purity levels. Thus, unlike the other materials, HPQ's geopolitical tensions stem more from market concentration than from trade restrictions. A few companies, mainly in the US and Norway, dominate HPQ production. While not currently under export controls, it is still a raw material of strategic nature and high interest for the semiconductor industry.

**Gallium** is used in compound semiconductors such as GaAs and GaN and also serves in doping processes and can be used to produce ingots and wafers. Gallium is not a primary element but a byproduct of aluminum and zinc production. Bayer liquor is the main and largest commercial resource for gallium extraction, while other smaller resources include recovery from red mud, electrostatic precipitator dust from aluminum processing, and gallium recovery from the dust of aluminum electrolysis plants (Lu et al., 2017). For explanations and reviews on even more processing techniques of gallium, the reader are directed to (Lu et al., 2017). Furthermore, while China dominates the global refining of gallium and produces the majority of low-grade gallium, it is still reliant on other countries for high-purity gallium. In 2023–2024, China introduced export controls on gallium, restricting supply and driving up global prices.

**Antimony** is a material used for doping silicon in microelectronics. It plays a niche but strategic role in semiconductor manufacturing. China has historically dominated the antimony supply chain due to its refining and processing capacity and infrastructure (Perpetua Resources, 2021). In 2017, China accounted for approximately 71% of global mine production, with major mining operations located in Guangxi, Hunan and Yunnan provinces. China was also producing the highest volume of antimony metal and oxides, importing the most antimony contained in ore and concentrates, and exporting more antimony metal and oxide than any other country (Klochko, 2017). However, the output from China has declined in recent years with a 16% decrease in 2017 compared to 2016, and 36% less than 2013. Despite this, China still accounted for 48% of global antimony mine production in 2023, remaining the leading producer (Klochko, 2025). As of last year, in 2024, China introduced export license requirements for several minerals, including antimony, which led to a sharp price increase. By December 2024, China had banned all antimony exports to the United States.

**Germanium** is used in semiconductors but maybe more common in infrared optics. Since germanium is too reactive to be found naturally, the material is extracted together with other substances (Scrreen, 2023b). The most common substances that germanium are sourced from are sulfide ores of zinc and coal deposits (Ruiz et al., 2018). Also, over 30% of global used germanium come from recycled processes. Germany and China have been key producers historically, but China currently dominates refining. In 2023, China announced export license requirements for germanium, tightening control over global access. As with gallium and antimony, this reflects broader trade tensions and dependencies on critical raw materials from a limited number of countries.

## 4.2 Current State of Supply Chain Knowledge, Dependencies and Risk Awareness

Currently, the reference company's visibility into its supply chain is strongest at Tier 1 and Tier 2 supplier levels, but limited beyond that. Some interviewees (Figure 3.1) mentions visibility into Tier 3, although knowledge and information at that stage is highly scarce and only exist at very few positions within the firm, mainly with those working with the topic daily. Through some internal interviews it became evident that the company lacks a lot of knowledge about the upstream supply chain. While the reference company is aware of the increasing risks facing global supply chains, particularly in the semiconductor sector, there remains a significant gap in understanding the deeper dependencies.

Recent disruptions, such as those triggered by the COVID-19 pandemic and ongoing geopolitical tensions, have increased the company's awareness of supply vulnerability. Yet, despite this growing risk awareness, there is limited insight into where the four raw materials originate, who controls the supply and extraction, and how such dependencies could impact production continuity. The company has expressed concern that it does not fully understand the degree to which it relies on specific regions or suppliers. This lack of visibility creates potential blind spots. While there is an understanding that the four semiconductor materials are critical, the pathways they take from raw extraction to final assembly remains blurry for the company. Only awareness that the materials are coming from Asia is to some extent well understood. The reference company currently lacks detailed mapping of its upstream supply chain, and therefore cannot effectively assess exposure to supply risks or environmental and ethical concerns tied to raw material sourcing and extraction.

Without understanding these dependencies, efforts to build resilience remain reactive and short-term, rather than proactive and long-term. Interviewee Sirius mentioned that *"Different people will see different challenges"*. It was meant that it has to be a severe and known risk to be able to make it to the decision table. Therefore no one will bring the raw materials to the table. Understanding the supply network of semiconductors from the company's viewpoint, and particularly the upstream chain, would therefore enhance resilience strategies and enhance supplier relationships by being able to ask the right questions to suppliers.

When asking interviewees from the first round what current challenges each individual saw as threats, different views came across. Sirius mentioned production capacity and linked it to high lead times on components as well as raised awareness on geopolitical issues with China and export bans. Sirius highlighted concern over that everything is connected and affects many companies. This view aligned with interviewee Rigel and Vega who connected it to volume fluctuations as a concern for capacity constraints. This can also be related to interviewee Antares who raised awareness on the imbalance of supply and demand for semiconductors. However, Rigel mentioned buffer stocks and that some suppliers are investing in having a secured inventory. On the other hand, Altair also touched upon buffer stocks but mentioned that they can not build buffer stocks since the value chain is too long and difficult to control. Furthermore, some interviewees highlighted trade restrictions and natural disasters. However, only in a few interviews, the dependencies became evident as a risk. The majority highlighted access to raw materials as a risk but only some talked about the concentrations and origins. Interviewee Altair mentioned supplier footprint concentration and connected it to regions and was aware that at least gallium was at high risk today. Additionally, Capella took it further and stated *"If Taiwan falls, automotive falls"*, implying that everyone is dependent on TSMC.

Something that the majority agreed upon was the lack of transparency in the supply chain. It was highlighted how difficult it is to extract information from suppliers since it in some ways is their business secret, their way of doing business, that suppliers in that case would give away. Altair mentioned that the company have tried to backtrack the supply chain on their own but that it only works down to some degrees. The interviewee mentioned the difficulty and did not put a lot of faith in anyone succeeding with it.

Due to the lack of knowledge and need of a better understanding to the above mentioned topics, the research came to put the focus on a supply chain mapping and the dependencies that exist on different levels within the semiconductor industry and its value chain.

# 5

# Empirical Findings

This chapter aims at describing the empirical results from the conducted desktop research and semi-structured interviews. It is split up into two sections, first describing the actors in the industry and secondly describing the geographical locations of extractions for each raw material.

## 5.1 Supply Network Mapping of the 4 Cases

This section presents an overview of the upstream supply network for the four selected critical raw materials relevant to the reference company and other automotive OEMs. The purpose is to map and visualize the core actors and locations of extraction that form part of the supply chain, from raw material sourcing to integration into automotive components. The mapping helps identify key dependencies, geographical concentrations, and potential points of vulnerability in the supply network. The first part outlines the main actors involved across different supply chain tiers, while the second part highlights the primary extraction regions and countries for each material.

### 5.1.1 Mapping of the Core Actors in the Supply Network of the Critical Raw Material to the Reference Company

For the mapping of the core actors, the downstream supply chain was more or less already known by the reference company. However, the upstream supply chain was not. Figure 5.1 demonstrates the key actors that the authors in this study have been able to find and deem critical and highly relevant. The shown companies are also those with the highest possibility of being part of the majority of semiconductor supply chains for automotive, according to the findings from desk research and interviews. The figure also displays links between extraction countries and its corresponding material. In this illustration, only the major ones are shown.

The figure shows an overview of the situation and is not fully representable for the whole semiconductor supply chain. The majority of interviewees mentioned a lack of transparency in the supply chain, which also became evident for the authors. Due to this, it was difficult to map a supply chain of actors that are certain to be in the supply chain for the reference company. Thus, the figure gives a hint and acts as an eye-opener. To see actors present in the upstream of the four raw materials, the following sections goes more deeply into this.

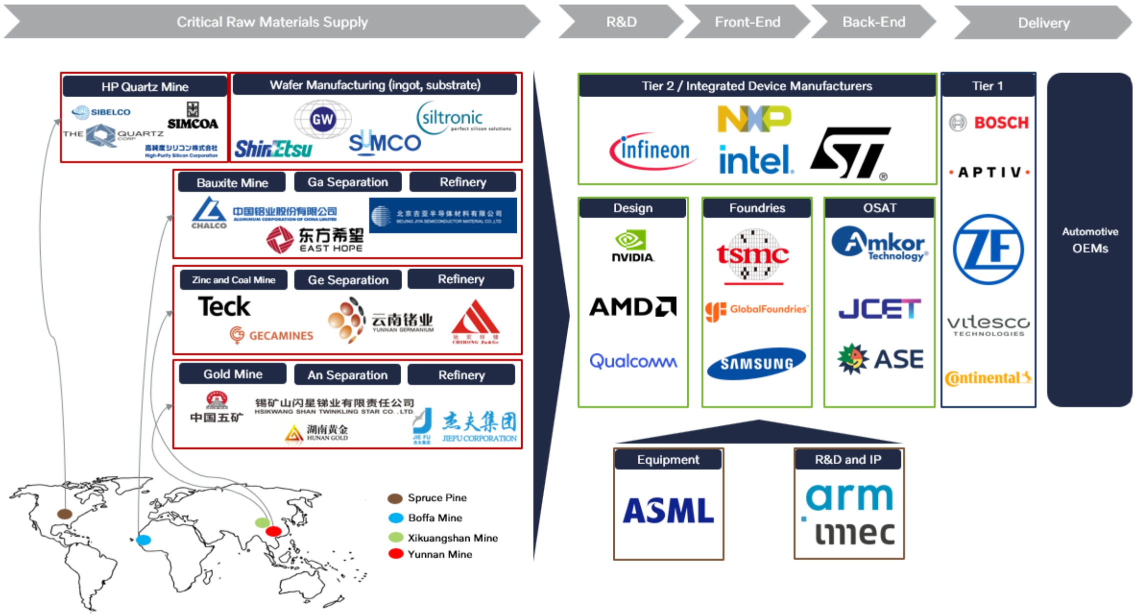


**Figure 5.1:** Author's of the mapping of key actors in the supply chain of semiconductors. Source: reference company and own research

#### 5.1.1.1 Mapping of the Core Actors in the Supply Network of High-purity Quartz

Going deeper into the supply chain of High-purity Quartz, Figure 5.2 shows the key actors for this part of the value chain. This picture is a deeper look compared to Figure 5.1 and includes the steps necessary to produce a silicon wafer.

During the interview with Venus who is part of the silicon wafer manufacturing stage, the illustration was shown. Venus responded to the picture with *"I think you got everything about right"* and meant that all actors are well known to be suppliers for each stage in the figure. Venus also mentioned some other important suppliers which were then added and included in the figure. The relationships and ownerships between actors was also well known for Venus, who stated that *"Hemlock is partially owned by ShinEtsu"* demonstrating that if one firm goes with ShinEtsu as a wafer and ingot producer, its likely that Hemlock (HSC) was the sub-supplier. Venus was also aware that the ownership of the quartz mining company Simcoa from firms such as ShinEtsu might have changed since it tend to change quite often (ShinEtsu, 2009).

Furthermore, when discussing the Chinese semiconductor landscape, Venus mentioned that China do have their own semiconductor industry, but that they are probably a generation or two behind the rest of the world. Venus stated that *"the rest of the world tend to stick with the links of Hemlock, Wacker or Tokuyama for* *their source of SMC grade silicon"*, meaning that suppliers outside of China tends to choose suppliers outside of China. The final stage for a wafer before receiving microchips on top is usually TSMC. Venus stated that *"TSMC will buy their wafers from ShinEtsu, from Siltronic, from Sumco, from Global Wafers"*, and meant that TSMC will tell a supplier that they want wafers from specific wafer suppliers, depending on the application. In the annual report by TSMC, wafer suppliers were said to originate from Taiwan, Japan, Germany, and Singapore (Huang, 2024).

Moreover, Venus mentioned that *"The majority of Chinese polysilicon manufacturers is actually directed toward solar cell manufacturing"*. Figure 5.2 shows that there is at least one major quartz producer in China, The Pacific Quartz Company. Hence, it was implied that quartz from China is more likely to be included in solar cells, although one can never be sure. When asked where quartz is supplied from, Venus mentioned the main source to be Australia, which could be Simcoa, but that there is also other sources in North and South America and also Norway.

Interviewee Venus also highlighted a natural distrust between Japan and China, leading Japan to generally avoid Chinese suppliers. Interviewee Haumea added that Japan is a strategic country that has for a long time been importing and stockpiling essential materials to reduce reliance on countries like China.

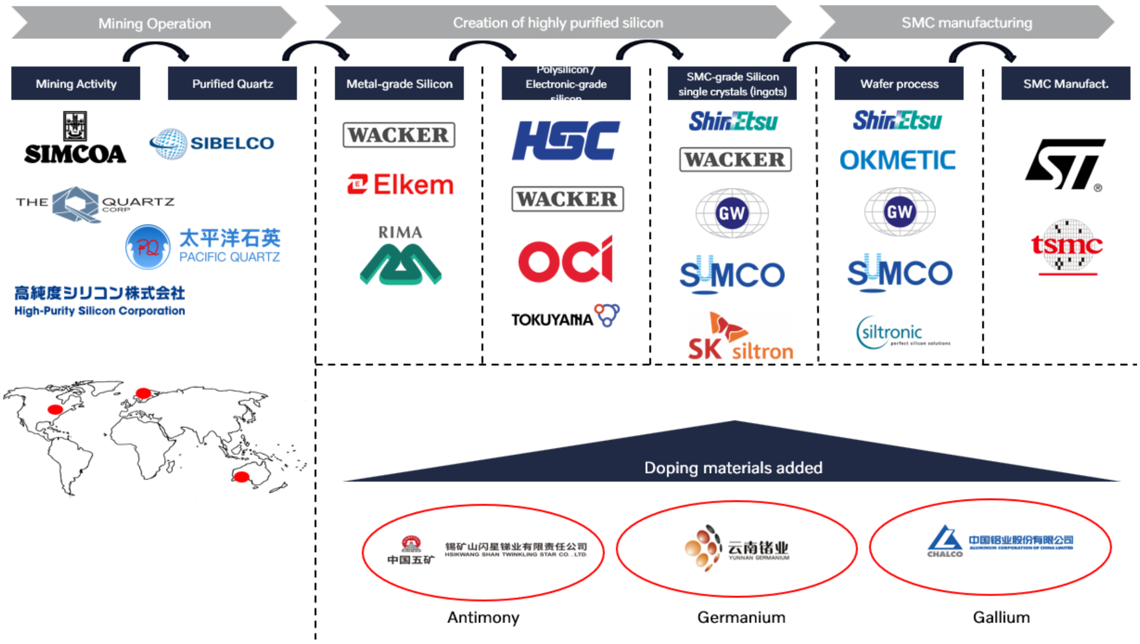


**Figure 5.2:** Author's own mapping of key actors in the supply chain of high-purity quartz for producing silicon wafers

It was a confusion both within the reference company and during the desktop research regarding where the doping materials antimony and germanium enter the supply chain. Venus stated that *"When we have grown the single crystal ingots, that is when we add the dopants"*. Thus, the big arrow pointing in towards the ingot stage is where the materials enter. However, depending on the final components, materials can be added in various steps as shown in figure 4.1.

#### 5.1.1.2 Mapping of the Core Actors in the Supply Network of Gallium

To obtain gallium, one must either mine bauxite or zinc and then gallium is received as a by-product. At the first stage, it is of a low-purity classification and not suitable for usage in the electronic industry. For this it is necessary to further purify it to become high-grade gallium. From the market research, the mapping of companies can be seen in Figure 5.3. To see the other stages until it reaches the wafer, we refer back to Figure 4.1. From zinc, only a very small percentage goes to become gallium, meanwhile the majority comes from bauxite extraction. Firms such as Hydro mentioned in an email that they are not dealing with gallium. After that email, the company did not respond anymore. RioTinto however, are developing gallium, according to an e-mail (Indium Corporation, n.d.; Rio Tinto, 2024).

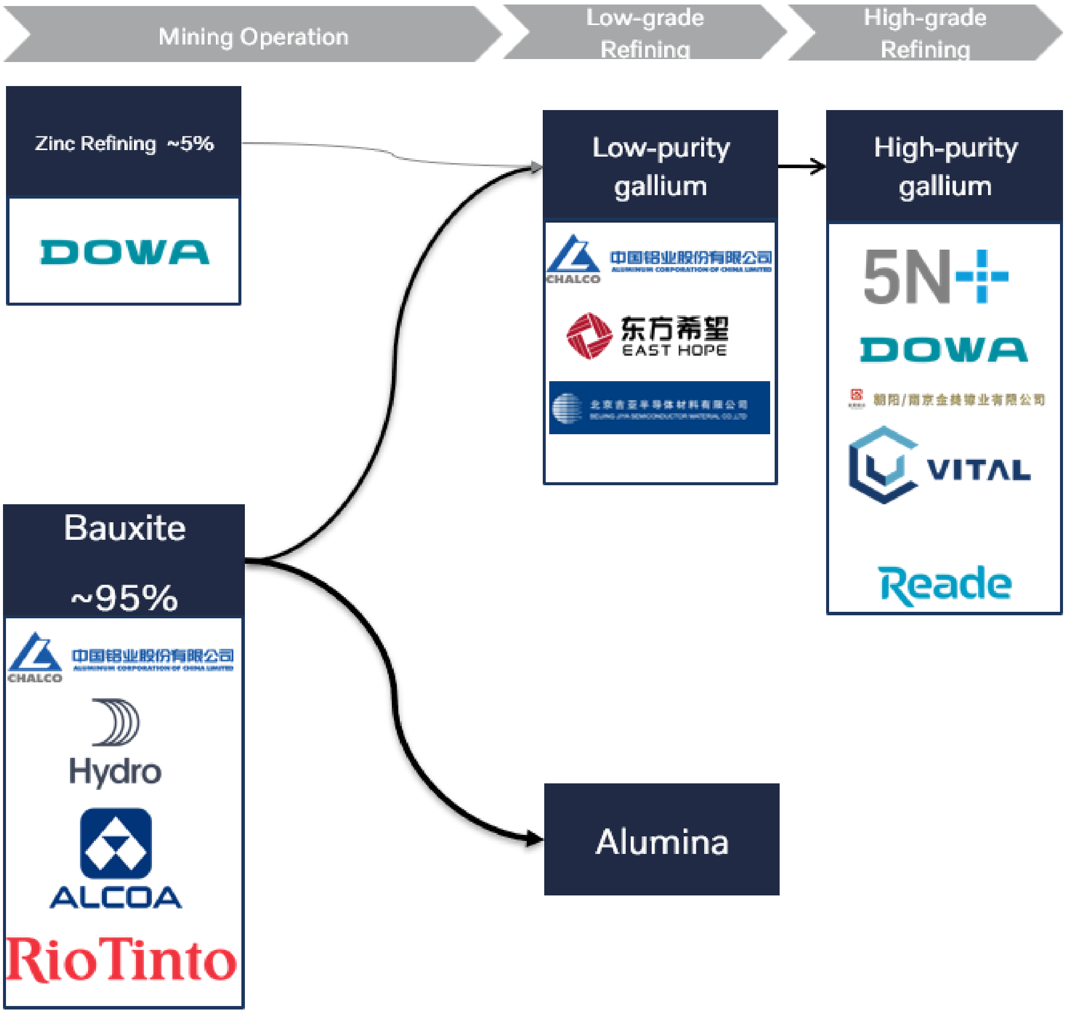


**Figure 5.3:** Author's illustration of core gallium actors in several supply chain stages

Companies dealing with low-grade refining of gallium includes primarily Chinese companies, with Chalco (Aluminum Corporation of China) being the leader. Chalco operates all the way from extracting bauxite to producing low-grade gallium. The others include East Hope and Beijing Jiya Semiconductor Material Co. Ltd (Mordor Intelligence, 2025c). As interviewee Haumea stated earlier, *“all those stuffs are owned by the government ”*, referring to mining and refinement companies. Moreover, what is then surprising is that when purifying further, no chinese companies are among the top ones of high-purity gallium, but mainly Japanese firms. 5N+, Dowa, Vital, JM-Gallium and Reade are among the major ones in this sector, with Dowa also being a zinc producer who obtains gallium as a by-product from that industry. Interviewee Haumea explained that over 80% of gallium demand falls in the low-grade purity range, meaning most applications don’t need ultra-high purity. Haumea continued and implied that China dominates the low-grade refining, but due to the smaller market for high-grade, it is likely not of interest. Hence, for ultra-pure gallium, China depends on imports, particularly from countries like Japan, which have better high-purity refining capability.

Since gallium is not used as a dopant but rather as a base material for GaN or GaAs wafers, there are different companies focusing on either one of them. For GaN, companies like Infineon and NXP emerged from the desktop research (Mordor Intelligence, 2025d). This was confirmed in one of the interviews. Although, this refers to manufacturing wafers, and not companies related to extraction. Therefore, it was only slightly touched upon but not part of the broader scope. However, those kind of wafers were not sure to be used in automotive. The semiconductor expert Tellus said *“I am not sure that gallium-nitride components are used in a truck”*. For GaAs wafers, Tellus mentioned that Europe has their own super important factory that are not allowed to go bankrupt even though competition from USA are fierce. An agreement has been made between some European countries that will enable the factory to continue its operations. This company is called UMS and it is a great example according to Tellus where Europe decides to not put their faith in other continents. Tellus means that to not be dependent on others, we can not lose this factory.

#### 5.1.1.3 Mapping of the Core Actors in the Supply Network of Antimony

For antimony, a figure of supply chain steps has not been made, as opposed to the prior sections. As stated earlier, antimony is used as a dopant and thus included in the supply chain once it reaches the ingot and wafer stage, as interviewee Venus mentioned. However, the scope was not to map processing steps but to map actors. During several interviews, and especially with Mercury, it was stated that it is very likely that an actor that does mining also does some processing and refining steps.

One finding concerns the actual criticality of antimony for semiconductors. Initially, the reference company considered antimony highly important, which was the primary reason for including it in the study. However, several interviewees expressed surprise and questioned the material’s level of criticality. Tellus said *"I don’t think antimony is a particularly critical element in a supply chain because it’s used so* *extremely little. It's used in infrared (IR) applications."* and Venus said *"It is quite an unusual dopant, maybe used 5% or so"*. Tellus meant that it is hard to work with due to the large size of the atom, which easily causes defects in the silicon. Therefore, other elements are preferred to use as dopants instead. Additionally, Mercury highlighted antimony as a strategic material for the defense and military industry rather than part of a semiconductor supply chain for automotive.

However, the findings of the core actors for antimony turned out to be highly concentrated in China. The largest core actors gained from the market and desktop research were Hsikwang Shan Twinkling Star Co. Ltd, Jiefu corporation, Yunnan Muli Antimony Industry Co. Ltd, Yiyang City Huachang Antimony Industry Co. Ltd and Hunan Gold (Brink et al., 2022; Mordor Intelligence, 2025a, 2025b). This aligned with Mercury who stated that *"Some key mining producers are Hsikwang Shan Antimony and Yunnan Muli Antimony. They basically dominate the market when it comes to antimony, not just extraction, but also smelting"*. Mercury also mentioned that there exist some big names outside of China, with Mandalay Resources in Australia being one player which get antimony as a byproduct from gold mining. One aspect that Mercury brought up regarding other companies that extract antimony was that it usually is run by Chinese companies anyway. It was stated that *"We do have extraction of antimony in Canada and it's being performed by Chinese consortiums as well. They are everywhere"* and that Tajikiztan has a company as well but that it is a joint venture between them and China. Haumea also mentioned China being the main country with companies extracting and refining antimony. In the interview, Haumea mentioned that *"All those stuffs they are owned by the government /.../ in principle you don't have any chance as a private company"*. Haumea meant that in China, the government owns the majority of businesses that are crucial and seen as important.

One interesting finding was that while digging in company reports, some indications of what suppliers are present in the chain can be seen. In an annual report from TSMC, suppliers of raw materials and minerals can be seen in a large list (Fang, 2023). When investigating some of them, Jiefu Corporation, as written about above, was found to be one supplier to the company. While this confirms at least one supplier's role, it suggests that other listed suppliers may also be key actors in TSMC's supply chain.

To give the reader a hint of the split share of the antimony industry in the world and relevant companies, the illustration made by Brink et al. (2022) provides a great visualization. This can be seen below in Figure 5.4. The figure displays the links with nodes between actors and locations. Geographical locations of mines will be displayed further down in this chapter.

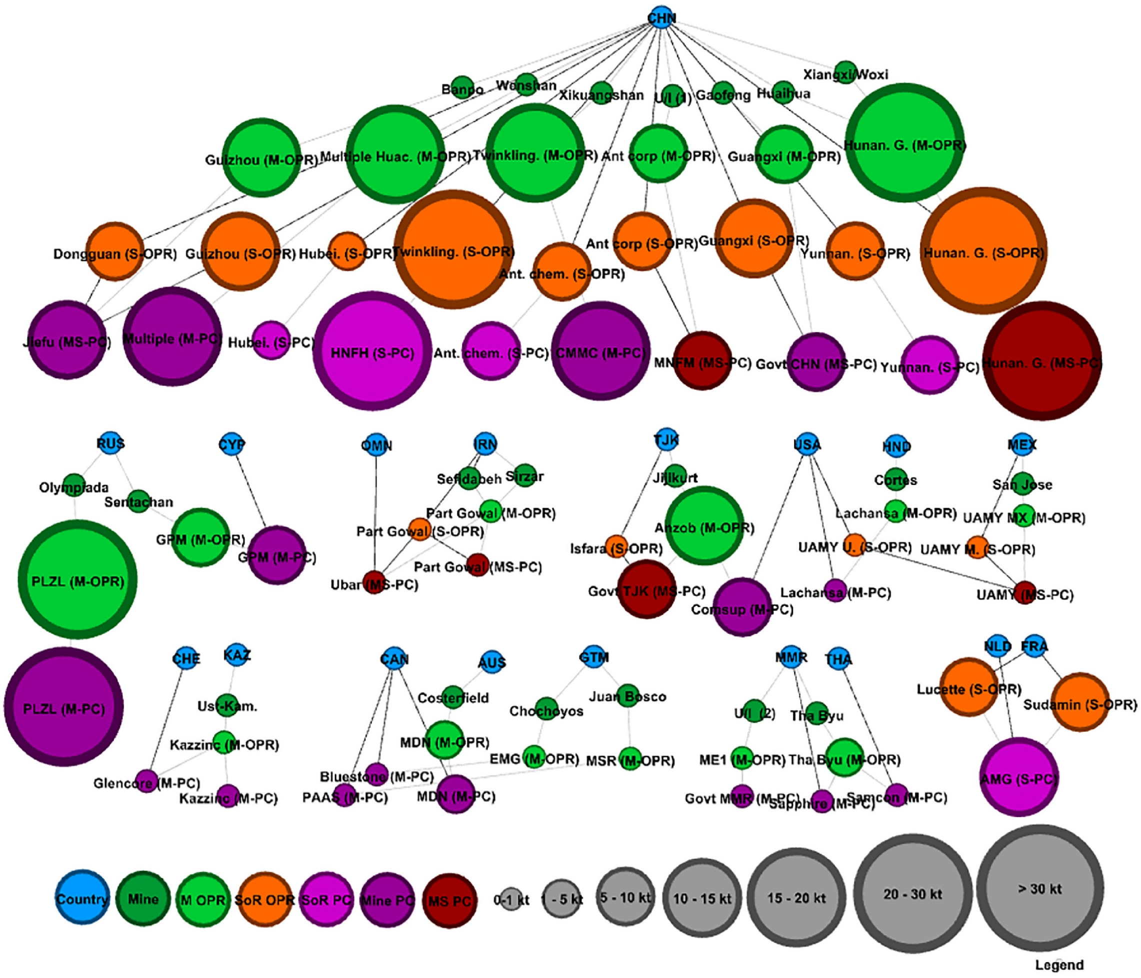


**Figure 5.4:** Brink et al. (2022) illustration of supply chain links between antimony companies

#### 5.1.1.4 Mapping of the Core Actors in the Supply Network of Germanium

The mapping of germanium resulted in a few companies being considered core actors. However, to obtain germanium, it has to be extracted as a by-product from zinc or coal mines, if not as a secondary recycled material. The flow of material and core actors mapped by the authors can be seen in Figure 5.5. The last stage in the figure are companies already described in the high-purity quartz section above.

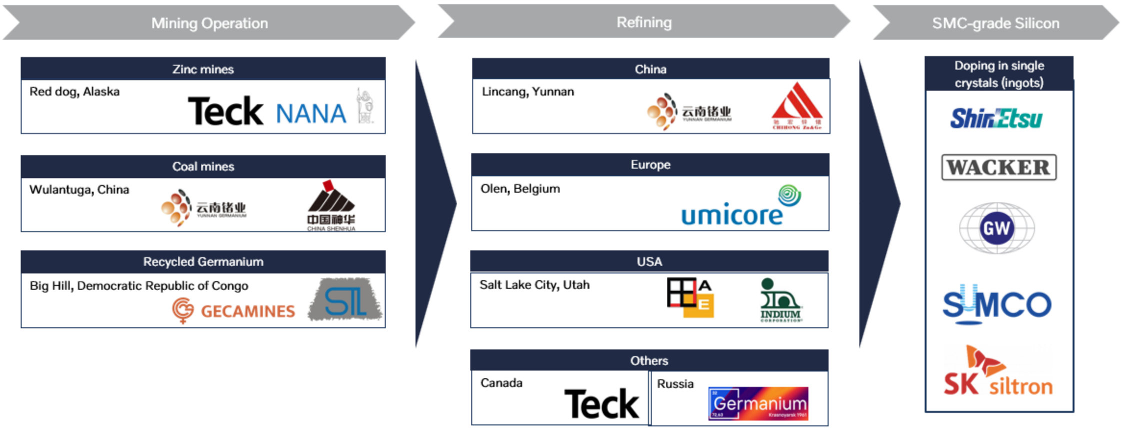


**Figure 5.5:** Author's illustration of core germanium actors in several supply chain stages

The mapping was made from the market research from multiple sources and interviews, aligning with the findings from for instance Mordor Intelligence (2025e) and The Diggings (n.d.). The major company in China is Yunnan Germanium which also is involved in refining. Other mining firms outside of China include Teck who is mining zinc and STL who claims to have 30% global market share of germanium (STL, 2025). Refining firms include Umicore, Indium Corporation and once again Teck.

There is an ongoing project for building up infrastructure to supply the European germanium market. This is done by Umicore in Belgium who are to receive germanium from the Democratic Republic of Congo (Umicore, 2024a). The germanium is before reaching Umicore treated by STL, also part of the Figure 5.5.

### 5.1.2 Mapping of Extraction Locations for the Critical Raw Materials

This section presents the geographical locations and concentrations of the four different raw materials in focus for the study. It demonstrates which countries are holding an upper hand in the market and how concentrated the market is for some of the materials. The section is split into subsections for each material.

A repeating pattern for each subsection is the Chinese dominance in refining and processing capability and market shares. During a lot of interviews, this did not come as a surprise. Interviewee Mars stated that *"The refineries being almost 90% in China, is absolutely quite right I would say because this is the reality for most materials. The reason is because China has the infrastructure to do it"* and Mercury replied *"If you take all of the rare minerals or critical minerals, China dominates the refining and processing of everything. /.../ This is a strategy that they have built over decades, so it is not short term but well calculated apparently"*. When asking why this is the case, the replies were uniform. It is a strategic move from China. However for some it is seen as a mistake from the rest of the world. Uranus stated

*"West have built up China my whole life, it is quite bothering"* and Mars stated *"In the 2000s, the US and Europe had started looking into refining but then they did not think it would be needed at the moment because they did not expect this kind of growth in the tech industry. They did not think that this would be needed. But China did it. That is why there is a bottleneck at the refineries"*.

#### 5.1.2.1 Extraction Locations for High-Purity Quartz

High-purity quartz is needed to produce electronic grade silicon that is used in semiconductors (Petiot et al., 2015). The supply chain stages are described in Figure 5.2. Petiot et al. (2015) stated in 2015 that there are no available data on reserves globally but that there are enough resources to meet the demand of the world for the coming decades. Today it can be found that the largest mine for high-purity quartz in the world is located in Spruce Pine, North Carolina, USA (Maxton, 2024). Mines are marked in yellow in Figure 5.6. The area is known for its high-purity quartz, and according to Zhao et al. (2024) enabled the United States to dominate the international market with this specific material. Today, they hold close to a monopoly of high-end quartz sand products (Adams, 2024; Fact.MR, 2024; Morphy, 2024; Tyson, 2024). Sibelco (previously Unimin) and The Quartz Corp are current extractors at the site (Petiot et al., 2015). Sibelco is a Belgium-based company, and The Quartz Corp is a partnership between the France-based company Imerys SA and the Norwegian firm Norsk Mineral AS (Warden et al., 2024). Spruce Pine has an output of 10 000 kt a year, followed by Drag in Norway and Moora in Australia with annual outputs of 267 kt respectively 50 kt (Maxton, 2024; NGU, n.d.).

Refineries of metallurgical grade silicon is primarily located in Norway and Brazil (Scrreen, 2023a). Following step of electronic grade occurs in The US, China, Japan, South Korea and Germany. The ingot growth is mainly based in Usa, Japan, Indonesia and Italy. The final step of creating wafers happens in USA, Japan, Germany, Singapore and South Korea. The countries which are stated are those countries which the companies in Figure 5.2 operates their factories in.

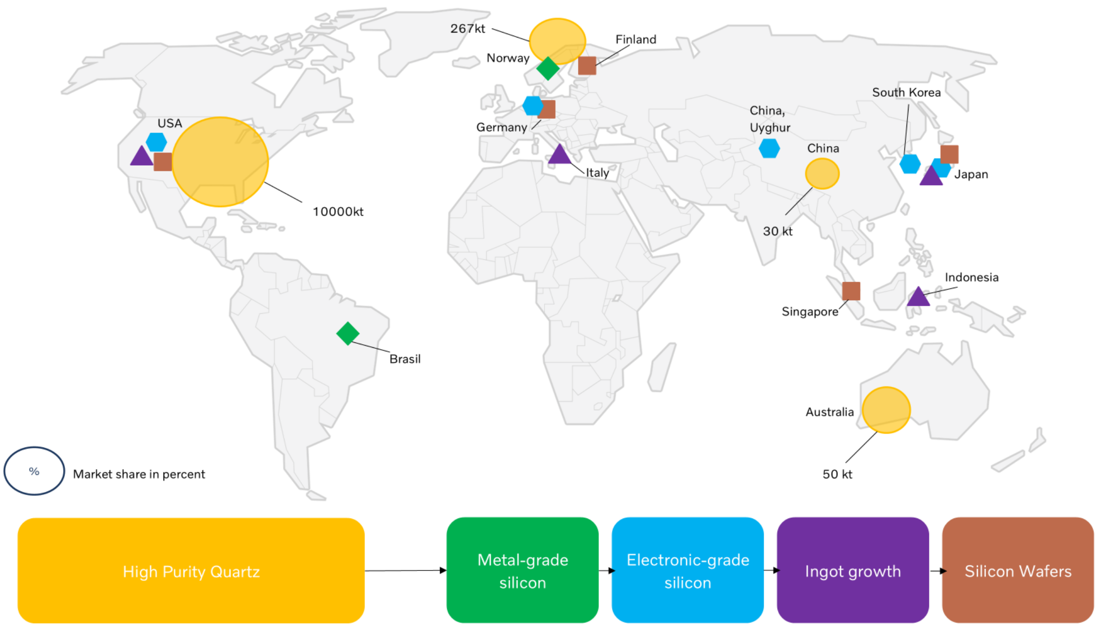


**Figure 5.6:** Author's illustration of High-Purity Quartz mines and refineries (Crawford & Murphy, 2023; Maxton, 2024; NGU, n.d.; Petiot et al., 2015; Scrreen, 2023a)

According to Venus, actors tend to source local materials due to quality standards. Previous attempts of sourcing ingots from another supplier has failed due to quality issues. The interviewee means that the market is not mature enough to share suppliers on short notices, and good relations between clients and suppliers are a necessity.

In the same interview, a region identified as a problem area was the Uyghur region in China. The area is said to use forced labor and modern slavery, and being 100% powered by coal. This is supported by Crawford and Murphy (2023), an investigating article about the region. Venus described how companies claim they are not sourcing from the area after being informed about the situation. Still, Venus is unsure if it can be trusted. The interviewee mentioned that *"Our supply chain tends to be fairly clean"* and also highlighted that the company pay very close attention to the region, and other risk areas as well.

#### 5.1.2.2 Extraction Locations for Gallium

The major actor in China that are in control of the most output of low-grade primary gallium is Aluminum Corporation of China (also known as Chalco or Chinalco) with refineries in South China's Guangxi Autonomous Region and the eastern Shandong province (Jaskula, 2021). The gallium production by country in the latter years can be seen in Table 5.1.

| Country | Primary Production 2023 (kg) | Primary Production 2024 (kg) | Production Capacity (kg) |
|---|---|---|---|
| China | 621,000 | 750,000 | 1,000,000 |
| Republic of Korea | 3,000 | 3,000 | 16,000 |
| Japan | 3,000 | 3,000 | 10,000 |
| Russia | 6,000 | 6,000 | 10,000 |
| Other countries | – | – | 88,000 |
| United States | – | – | – |

**Table 5.1:** Gallium Primary Production and Production Capacity by Country, data from (Dair, 2025)

Since gallium is not a primary resource in nature and comes from bauxite, the mines does not necessarily comes from China. Data from Merrill (2025) shows that the major global reserves are located in Africa, and China relies heavily on imports of bauxite besides their own operations with close to 70% import reliance (SMM, 2023). Chalco, the major Chinese aluminum company, is operating outside the Chinese borders in Guinea, at the Boffa mine. Additionally, China has some locations where bauxite can be found domestically (Gu, 2016). These mine deposits can be found in such provinces as Shanxi, Henan, Guizhou and Guangxi. Most of the mines are located in these four provinces and account for 90% of the bauxite mine (Gu, 2016).

| Country | Bauxite Production 2023 (tons) | Bauxite Production 2024 (tons) | Bauxite Reserves (tons) |
|---|---|---|---|
| Guinea | 123,000 | 130,000 | 7,400,000 |
| Australia | 104,000 | 100,000 | 3,500,000 |
| Vietnam | 3,920 | 4,200 | 3,100,000 |
| Indonesia | 30,000 | 32,000 | 2,800,000 |
| Brazil | 32,000 | 33,000 | 2,700,000 |
| Jamaica | 6,000 | 6,000 | 2,000,000 |
| China | 91,000 | 93,000 | 680,000 |
| India | 23,400 | 24,000 | 660,000 |
| Kazakhstan | – | – | 280,000 |
| Russia | 5,800 | 5,800 | 280,000 |
| Turkey | 2,940 | 3,200 | 69,000 |

**Table 5.2:** Bauxite Production and Reserves by Country (Sorted by Reserves), with data from Merrill (2025)

As showed in Figure 5.7, the sources of bauxite supply is widespread across the world, with Guinea being the largest actor, producing 29% of the total output annually (Merrill, 2025). The other large players include Australia, China and Brazil and Indonesia with an equal output. The second step involves refining the gallium, which first becomes low-grade gallium. It is evident from the figure that China holds an absolute monopoly with 99% of the market share for this type of gallium (Dair, 2025). As a third step, gallium must be further refined into high-grade gallium, which is done more or less around the globe. Figure 5.7 displays the countries for this step, but also here is China the biggest in terms of market share (European Commission, n.d.). The blue circles displays both primary and secondary high-grade production, which involves recycling as well, and thus it should be taken as a sign of awareness rather than the actual reality. One relevant finding regarding to this is that interviewee Jupiter mentioned that the company does not source gallium at all from China.

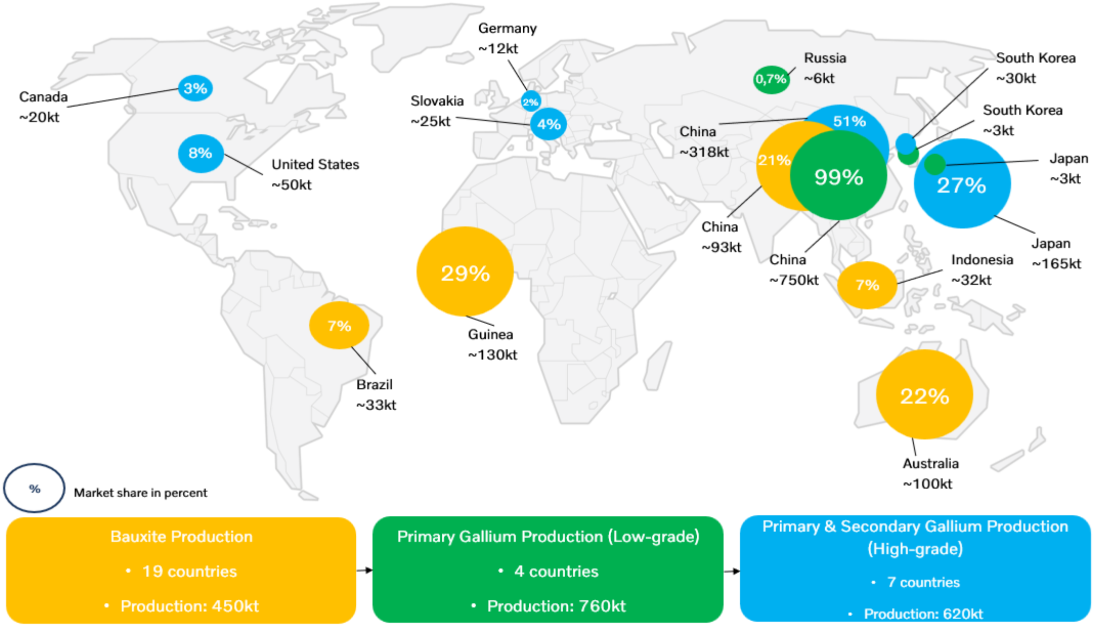


**Figure 5.7:** Author's illustration of the global view of mines and refineries for gallium (Dair, 2025; European Commission, n.d.; Merrill, 2025)

### 5.1.2.3 Extraction Locations for Antimony

China today has depleted some of its main mines and relies heavily on imported antimony concentrates mainly from Russia and Tajikistan (Perpetua Resources, 2021). However, China has secured control in several mines located in other countries such as Murchison Belt in South Africa and mines in Bolivia, Australia, Tajikistan and Canada. Nevertheless, new refining facilities in Oman, the Strategic & Precious Metals Processing project, could diversify supply away from China with an annual capacity of 20,000 t of antimony products (Perpetua Resources, 2021). Interviewee Mercury highlighted this project and also mentioned Myanmar as a country with future projects for antimony. However, Mercury in relation to this also stated that China imports antimony due to its depleted mines and problems with quality and volume output. Quite no surprise, Mercury meant that the import comes from Myanmar.

In December 2024, China banned all exports of antimony to the USA (Lv & Munroe, 2024). The production and reserves of the top producing countries can be seen in Table 5.3, showing the dependencies the world has on a few countries (Klochko, 2025).

| Country | Mine Production 2023 (tons) | Mine Production 2024 (tons) | Reserves (tons) |
|---|---|---|---|
| China | 62,300 | 60,000 | 670,000 |
| Russia | 13,000 | 13,000 | 350,000 |
| Bolivia | 3,700 | 3,700 | 310,000 |
| Kyrgyzstan | 20 | 20 | 260,000 |
| Australia | 1,860 | 2,000 | 140,000 |
| Burma (Myanmar) | 4,500 | 4,500 | 140,000 |
| Turkey | 1,600 | 1,600 | 99,000 |
| Canada | – | – | 78,000 |
| United States | – | – | 60,000 |
| Vietnam | 300 | 300 | 54,000 |
| Tajikistan | 17,000 | 17,000 | 50,000 |
| Pakistan | 250 | 250 | 26,000 |
| Mexico | 800 | 800 | 18,000 |

**Table 5.3:** Antimony Mine Production and Reserves by Country, data from (Klochko, 2025)

As seen in Figure 5.8, Antimony is extracted mainly in three countries; China, Tajikiztan and Russia (Klochko, 2025). In total, 17 countries are mining antimony but only the biggest are displayed in the illustration below, with a total output of 100 kt and China controlling 60% of the market share as of 2025 data from Klochko (2025). After mining operations, antimony is sent to smelters and refineries, which are also highly concentrated in China, holding an even greater market share of 79%. However, there exist other countries capable of refining antimony in Europe. These are mainly France and Belgium with a capacity of refining 12 respectively 9 kt (Brink et al., 2022). In total, eight countries are found to be smelting and refining antimony, with six additional potential countries capable of doing it. These are countries where production either has seized operations or are underway of building infrastructure and capabilities (Brink et al., 2022). The annual output of refined antimony is 135 kt, which is higher than the mining output due to partly secondary refining. Brink et al. (2022) found that secondary supply such as recycling offer potential to diversify supply. This aligned with interviewee Mercury who stated that a large amount of antimony comes from recycling and could be retrieved from lead-acid batteries.

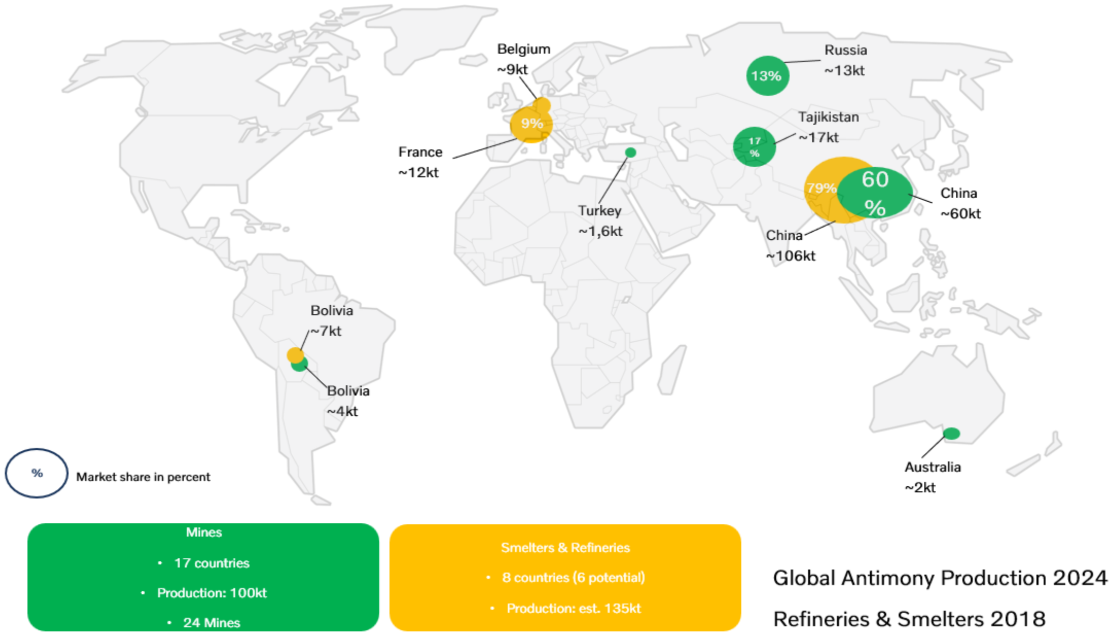


**Figure 5.8:** Author's illustration of the global view of mines, smelters and refineries for antimony (Brink et al., 2022; Klochko, 2025)

The majority of antimony has its roots in China, which holds the largest antimony mines known globally. The majority of deposits is concentrated in a few key provinces of China: Hunan (approximately 25.2%), Guangxi (20.9%), Tibet (14.8%), Guizhou (12.6%), Yunnan (9.4%), Gansu (5.8%), and Guangdong (2.4%), among others (Shanghai Metals Market, 2021). The worlds largest deposit in China is located in the Xikuangshan area near Lengshuijiang City. This area, located in the Hunan province, is referred to as the antimony capital (Dupont et al., 2016; Wang et al., 2011). The Hunan province accounts for 75% of China's total antimony production (Guo et al., 2014). The geographical location of the mine can be seen in Figure 5.9. The major company producing and mining antimony in this province is Hsikwang Shan Twinkling Star Co., Ltd, a state owned company located next to the mine, as stated earlier.

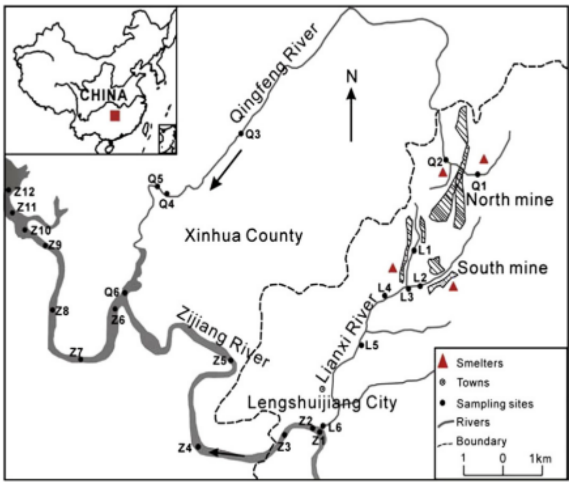


**Figure 5.9:** Sampling locations at Xikuangshan antimony mine (Wang et al., 2011)

When talking to interviewee Haumea about antimony extraction locations, the interviewee said that China has the biggest storage of antimony in the world. It was without doubt replied that Xikuangshan was the biggest mining area. Haumea said *"The largest antinomy mining is in China in Hunan Province. Every Chinese kid they know, this is like the basic knowledge"*. Also Mercury brought up this area as the largest one in the world.

However, Haumea mentioned that China do not always have the best technology to refine to extremely high purity levels or levels that are demanded by the market. Haumea said that *"China is very good for catching up, but they are not so good at the forefront, the technology forefront"*. On this note, in the interview with Mercury, it was also discussed that other countries in Asia do refining to support the regional markets, where Vietnam was brought up as an example.

Mercury noted that *"Back in the days, no one was talking about antimony"*. Today however, Mercury meant that almost everyone is talking about it. It was discussed that with depleting mines and resources, there is a need for recycled antimony. Mercury mentioned that one of the ways of getting secondary antimony is to recycle lead acid batteries and stated that *"If we could recycle everything that we have antimony in today, there is an estimate that we could meet approx 15 to 20% of the global demand"*.

#### 5.1.2.4 Extraction Locations for Germanium

Germanium is a by-product from zinc and coal, but not all ores bear germanium in a concentration worth to extract. Due to limitations in this data, all zinc mines globally are treated as potential germanium-bearing sites in this study. China holds the market with 33%, followed by Peru, Australia, India, Mexico and the US as in Figure 5.10, accessed from (Geological Survey, 2025). However, a *known* place of extraction for germanium are the Red Dog mine in Alaska, USA (Teck Resources Limited, 2025). Trail Operations, owned by Teck Resources Limited, refine Germanium. Teck Resources Limited operates in the Red Dog mine and has an output of 616 kt of zinc in concentrate and 256 kt refined zinc in USA annually, which supply Trail Operations with material to refine Germanium (Teck Resources Limited, 2025). However, the amount of Germanium produced by Trail Operations is not disclosed.

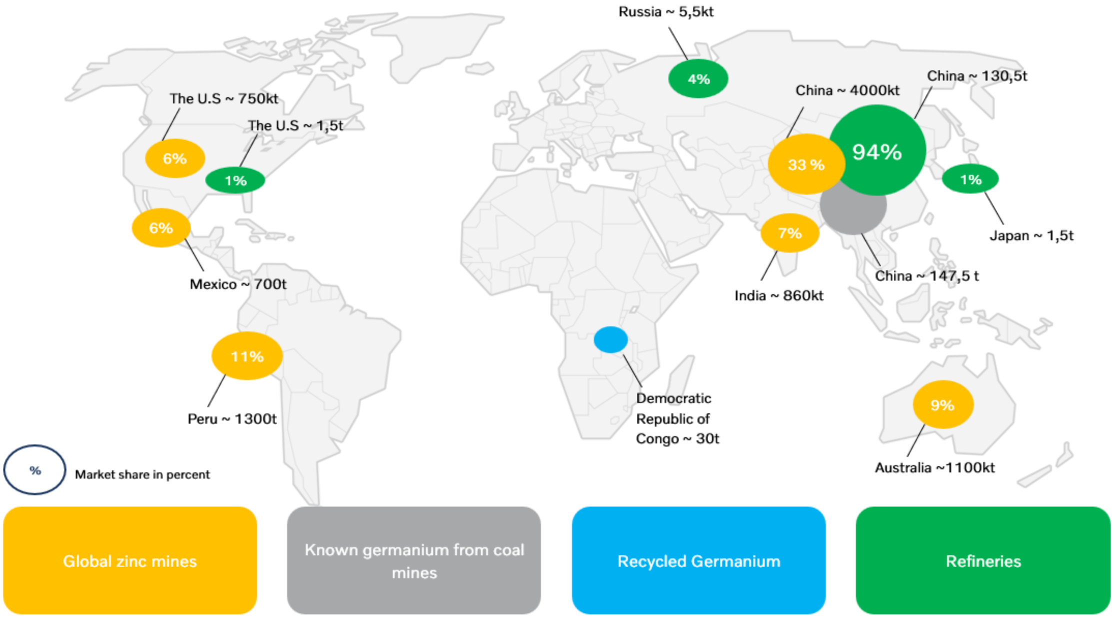


**Figure 5.10:** Author's illustration of the global view of mines and refineries for germanium (Patton D, 2023; Teck Resources Limited, 2025; Tolcin, 2025; Umicore, 2024b)

Known germanium-containing coal mines in China are Yunnan province and Wulantuga mine in Inner Mongolia. China has an output of approximately 148 kt germanium annually from coal mines (Patton D, 2023). Regarding refineries, China has a close to monopoly with 94% market share, followed by Russia 4% and lastly Japan and USA with 1% each (Tolcin, 2025).

The European Commission has two germanium-focused projects in their Critical Raw Materials Act (European Commission, 2020, 2025). Both projects are with Umicore in Belgium, and one of them is ReGAIN for recycling germanium. Umicore has signed a partnership with Gecamines and STL in The Democratic Republic of Congo, DRC (Umicore, 2024a). Additionally, interviewee Mars mentioned that in the context of the European Union, Sweden is important for zinc production and possibly to produce germanium. The reason is due to being a local mine and a potential supply for germanium in the future. However, according to SGU (2020), no extraction for germanium is being done in Sweden. There are germanium-containing ores in Sweden, but according to SGU the concentrations are not high enough to make extraction worthwhile.

Also germanium was brought up by a few interviewees as a material of low interest for semiconductors. Tellus mentioned that there exist germanium-wafers but very few and said that germanium is mainly used in the fabrication plants for only a few types of components mainly as doping materials on top of silicon.

#### 5.1.2.5 Major Bottlenecks

When summarizing the major bottlenecks found during the mapping of resources, four is considered severe enough to highlight. In Figure 5.11, the concentration of refineries in China for Gallium, Germanium and Antimony is highlighted, together with mines for Antimony and High-purity quartz. "No data" was assigned regarding high-purity quartz because no representative market share could be determined from the findings. However, analysis of outputs from annual reports and market research firms indicates that Spruce Pine, North Carolina, is the world's largest producer of high-purity quartz, which represents a potential bottleneck in the global supply chain. Nevertheless, the main and most severe bottlenecks are still the refining capacity and market dominance of China regarding the other three materials.

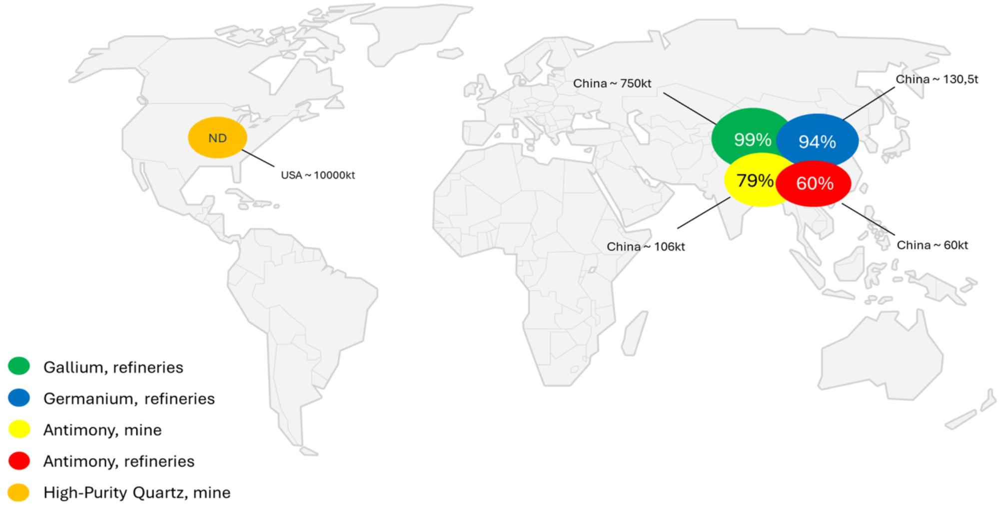


**Figure 5.11:** Author's Illustration of the Major Bottlenecks from the Mapping of Resources

## 5.2 Dependencies and potential risks

The knowledge, focus and interest of dependencies and potential risks are varied among the interviewees. Figure 5.12 presents the key findings related to dependency dynamics and risks in the upstream semiconductor supply chain, categorized in the system levels micro, meso and macro, introduced in the theoretical framework. The aim is to demonstrate different scales of dependencies, from firm-level to a broader global systems level. In other words, Figure 5.12 can be seen as a summary for what dependence dynamics is present for the different system levels, further explained in following chapters 5.2.1, 5.2.2 and 5.2.3.

The Figure 5.12 should be interpreted from left to right, showing the characteristics and power dependency sources related to each level (micro, meso or macro). The dynamics for each level is then displayed followed by the strategies implemented to reduce dependencies and strategies that respondents wish to be implemented to better cope with the dependencies. For each level, challenges are also displayed, as well as example quotes demonstrating or highlighting the observed dependencies.

| System level | Characteristics | Power Dependence Sources | Dependence Dynamics | Strategies Implemented to Reduce Own Dependence | Strategies Wished to be Implemented | Challenges in Reducing Own Dependency | Collected data | Example quote |
|---|---|---|---|---|---|---|---|---|
| **Micro** | *Individual firms*<br>Concerns day-to-day business and decisions | Organizational size, resources, and brand recognition (1,2) | Companies are dependent on recieving critical information from suppliers | Quarterly internal updates on market outlook and raw material risk monitoring by a central task force entity. | Total visibility of supply chain and potential risks (provided by suppliers) | High effort needed, low motivation to trace raw material origin if not at high (known) risk | Neptune | *“We have to balance effort and gain of investigating the upstream supply chain”* |
| | | | | | | | Haumea | *“It was never important where the raw materials came from.”* |
| | | Unique capabilities and internal expertise (2) | Dependent on a stable business without disruptions | Departments for risk monitoring | Total visibility of supply chain | Complexity and lack of visibility of upstream supply chain | Neptune | *"We have a central group that looks into our sub suppliers supply base"* |
| | | Reputation and demand share (3) | Companies are dependent on a stable supply of semiconductors, supplier-power | Supplier communication by leveraging a good reputation | Securing supply through strategic agreements | Small demand share of semiconductor market, supplier-power | Reference Company | - |
| **Meso** | *Network of organizations*<br>Interactions between groups, organizations and institutions<br>Influences between actors<br>Connects micro and macro level | Inter-organizational relationships and dependencies (2,4) | Partial ability to push suppliers | Multi/dual sourcing, component-level resilience | Strategic alliances (implied) | Extent to which strategies cascade to lower tiers can depend on network power | Neptune | *“We can replace suppliers and components quickly, but that does not eliminate dependency.”* |
| | | Control over key resources or information (5) | China and USA are interdepented on resources and high technology | China and USA export restrictions | Long-term thinking | Politics and pride | Haumea | *"China is using the export restictions in order to get the higher technology from USA"* |
| | | | The market is dependent on the refining capactiy of China | Political involvement and EU Critical Raw Materials Act | Faster permits for exploitation of new mining activities and recycling | Long waiting times for permits due to regulations | Mercury | *"There is a bottleneck at the refineries"* |
| | | | | | Local exploitation and exploration projects | | Mars | *bottlenecks at the source is to have local sources"* |
| | | Supplier network complexity and technological capability (6) | Actors have a preference for local, high-quality suppliers | - | Strategic alliances/cooperation during crisis | Quality barriers limit substitution | Venus | *“They were absolute rubbish”* |
| | | | European defence companies are dependent on certain locally produced microtechnology | Strategic business preservation (government intervention) | Support local and regional businesses | Big players in the market threathens the smaller | Tellus | *"If we lose it, we have no one left to produce these specialized chips. Swedish defense companies also buys from them, there’s a lack of trust in USA"* |
| | | Network structure and firm position (1) | Limited upstream insight, dependent on supplier information | Trust in supplier | More visibility (implied) | Supplier may not have the knowledge | Neptune | *" My main indicator is the feedback I get from my supplier directly"* |
| | | | | | | | Jupiter | *"We should not do the job of our suppliers"'* |
| **Macro** | *Large-scale structures*<br>Governments, global systems, trends, policies, trade regulations | Geopolitical shifts and disruptions (such as COVID-19) (7) | Global dependencies, everyone gets affected in case of misalignments | Being prepared for risk and crisis management | Long-term thinking | Short-term thinking | Uranus | *"It's more that the resources go somewhere else. A major war, for example, would really consume resources"* |
| | | | | - | Governments should put pressure on companies | Short-term thinking and focus on revenue | Mars | *"Companies tend to look at profit /.../ but there is a difference between long term and short term profit"* |
| | | Purchasing regulations (e.g., public procurement, corporate constraints) (8) | Tariffs | Constant monitoring | More transparency | Uncertain environment | Jupiter | *"We have to watch the news everyday"* |
| | | Economic trends and global market (9) | Market demand volatility | Collecting market information, internal communication regarding decisions | More visibility (implied) | Long cycles to put investments in place | Neptune | *"You need 2-3 years to build a factory and once you have the factory in place the market has changed"* |

**Figure 5.12:** Author’s table over summary of findings in different system levels in relation to power dependencies and dynamics

### 5.2.1 Micro dependencies

The power dependence sources in the micro system level are hard to separate from one another, and following dependence dynamics are to some extent overlapping. However, the two main dependence dynamics were found to be the need of internal coordination and information sharing for companies, together with operational stability. Consequently, companies are putting up strategies to share critical information within the organization, and having central entities that monitor known risks. *"We have a central entity that looks into listed critical materials"* (Neptune, May 2025). Jupiter states their firm is able to act when something becomes critical, and they are ready for risk management.

Also, organizations are dependent on internal initiatives to receive critical information about potential risks, that can be spread internally. Neptune explain that there is not enough knowledge or visibility at the moment to be aware of relevant dependence dynamics. On the other hand, Neptune discuss the balance between effort and gain of investigating in the upstream supply chain. Neptune mention that there is no constraint in the market at the moment, and is therefore unsure if the effort would pay off as of the situation today. Supporting this mindset is Jupiter, saying that semiconductors are not in capacity constraints right now and the firm is *"not freaking out at the moment"*. Mars is supporting this by discussing the difference between long and short-term profits, where companies tend to prioritize the last. Mars explains that technology and investments is required to secure a supply chain, and says that *"companies need to justify this on a short term. If they don't see a profit in the short term they tend to not change their processes or supply chain"*.

Jupiter explains that as long as the technical requirement is fulfilled, Jupiter don't see a problem regarding where the materials are sourced from. Haumea, which also is a previous buyer of some of the materials, means that *"It was never important where the raw materials came from"*. On the other hand, Neptune explains that *"over the last five years, everybody has suffered so much that now many companies put a lot of infrastructure, a lot of resources in place to avoid this type of situation again and to have a better understanding how your sub supply chain look like"* when talking about the consequences of COVID-19.

To summarize, organizations are dependent on internal initiatives and the motivation of getting critical information and investigate in the upstream supply chain, in order to be able to spread it across the organization and monitor risks.

### 5.2.2 Meso dependencies

In the meso system level, control over key resources and information is the most marked power dependence source, leading to various dependence dynamics. Interorganizational relationships, supplier network complexity and technological capability, network structure and firm position are also available power dependence sources.

The heavy concentration of refining capacity in China which can be seen as a control over key resources, creates a structural dependency across the entire supply chain, making more or less all actors reliant on Chinese operations. Mars validate that China holds the majority of the refining capacity in the world and states that *"There is a bottleneck at the refineries"*. Mercury states that China will continue to hold this power for a long time, since the rest of the world has no chance of catching up in the following 10-15 years. Mars explains that USA and Europe began exploring refining in the 2000s but didn't see the need for it, as they didn't foresee the rapid growth of the tech industry that has taken place since then. Consequently they didn't move forward, *"But China did it. That is why there is a bottleneck at the refineries"*. Technological capability is therefore another apparent source of power dependence here. Mars mean up that only certain people and locations have the material, skill and infrastructure to mine. *"If even one producer goes out of business or if there is an issue in one mine, it can disrupt the whole supply chain because the material is finite, the number of people that have the expertise to work with the material is finite, the infrastructure for the material to process is limited as well"* (Mars, April 2025).

Mars further talks about China's road and belt plan, which *"basically looks into how they can develop their resource base and includes investments into other countries"*. On that note Mars continues explaining that one need to be conscious about two different types of ownership by China, the physically owning or the financially owning. Mars brings up an example with DRC, where China are paying for the extraction and processing *"so then it becomes their material. But in reality, the location of the material is the DRC"*. Uranus witness about that *"The West have helped in building up the infrastructure in China my whole life"*, and that they are recruiting aggressively in specialized competences. For example, Uranus have seen colleagues getting attractive offers to go to China and work with semiconductors. To summarize, the world is dependent on the refining capacity of China and its control over key resources and information, together with their technological capabilities and competence.

Another dependency dynamic is between the producers of wafers and the suppliers of the raw material. Venus explain that actors in the market *"don't tend to exchange ingots"* due to high expectations on quality. During the shortage, Venus firm tried to buy ingots from another company, but *"they were absolute rubbish"* and the firm was unable to use it. Venus also witness of local supply being favorable, together with relationships being an important aspect of what suppliers are chosen. Venus expresses a wish for being able to cooperate in the industry during disruptions, but expresses skepticism about its feasibility in practice. Therefore it's evident that some players are dependent on certain technical requirements, and need to build up a network of suppliers over a longer time that can deliver the right quality.

Another dependency dynamic that emerges from technological capability, is the European defense companies that are dependent on certain locally produced micro technology. Tellus talks about the importance of securing supply of certain technologies and how countries can go together to save strategic businesses, even if they are threatened by the market. Tellus brings up an example of a case where Europe, with

France and Germany in lead, has decided not to let a certain company go under. The company United Monolithic Semiconductors produces high-speed technology for European fighter air crafts and is under pressure from American competitors. *"If we lose it, we have no one left to produce these specialized chips. Swedish defense companies also buys from them, there's a lack of trust in USA"* (Tellus, April 2025). The semiconductor fab of UMS is considered a strategic business for France, Germany and Europe as a whole, and is therefore according to Tellus under protection. This shows how strategic business preservation through governmental intervention can work towards mitigating a dependency.

Neptune share that their company is trying to reduce dependencies through different procurement strategies and said that *"We have already identified multiple, dual or multi sourcing so we can replace suppliers and components quickly. But that does not completely eliminate your dependency"*. How Neptune's firm typically works with resilience and second sourcing is to look at the component level, what is possible replacement parts and is there other suppliers that can offer similar solutions. *"My suppliers, as far as I know, they all have contracts with I wouldn't say many, but several companies, and they don't depend on one company anymore. So that makes you feel a little better because you're less dependent"* (Neptune, May 2025). Neptune reveals that a next-level investigation about what material exactly goes in to the components does not exist today. Neither do Neptunes firm investigate any dependencies on the sub suppliers. On the other hand Neptune mean that it exist *"a central group that looks in to our sub suppliers supply base. But this is limited to conflict minerals and relatively small group of raw materials"*. The strategy of Jupiter's firm to go around the concentration of gallium refineries is also multi sourcing. Additionally, Jupiter claim that they do not source any Gallium from China, after seeing the mapping of the resources.

Network structure and firm position give rise to companies having limited upstream insight, and therefore is dependent on supplier information. Due to this, companies are left with the only choice of trusting their supplier. Neptune believe that suppliers have a lot of information regarding the upstream activities and potential risks that they are willing to share; *"Maybe not in all details, but a high level summary and overview and trend I think yes, that's something I would expect from my suppliers"* (Neptune, May 2025). Jupiter states that *"We should not do the job of our suppliers"'*, and puts the responsibility on suppliers to investigate in upstream supply chain. Neptune also proposes an answer to why suppliers sometimes tend to not display the difficulties of the market today: *"You don't want to go to your customer and just say I have a problem because then what happens? Your customer is more concerned and ask you more questions. So whenever you may have identified a problem you want to have at least an idea how you can solve it"*.

### 5.2.3 Macro dependencies

In the macro system level, large shifts, regulations, politics, trends and disruptions causes dependency dynamics to occur. Economic trends and the global market are two sources of great importance, where the interviewees talks about investments being adapted and the large focus in revenue. Geopolitical shifts and disruptions is also at high focus, together with purchasing regulations from governments, such as tariffs and export bans.

Companies make choices depending on the market outlook, which makes them dependent on market trends and consumer willingness. Neptune witness of a conversation every quarter around the market outlook. Collecting information, sharing information and communication is important according to Neptune since *"that will have an influence on who we select and which technology we select for our next generation product"*. The volatility of the market demand is one dependency present, where Neptune talks about how the fluctuations affects companies. Neptune mean that demand increased during the pandemic, and suppliers today have free capacity since the market has developed slower than expected. *"In semiconductor business you have relatively long cycles to put investments in place. You need 2-3 years to build a factory and once you have the factory in place the market has changed"* (Neptune, May 2025). Neptune mean that the market demand and consumer-willingness to buy is one of the strongest dependencies the firm experiences of today. Neptune witness of an decreased demand for European and North American OEM's producing electric vehicles, and *"It doesn't feel good to be in this type of dependency"*.

Following on the economic trends and global market, Uranus points out that everyone is driven by the desire to make money. This is supported by Haumea, who talks about companies in China: *"If it is a state or if it is a private owned company, they want to earn money. That's the most important"*. Haumea also mean that all companies in China who operates in the mining and refining sector are owned by the government since private companies *"don't have any chance"*.

Despite possible geopolitical shifts and disruptions, Uranus expresses confidence in the continued stability of material production since *" There will always be someone who wants to sell"*. However, Uranus suggests that resources may be redistributed and concentrated in certain areas due to a shift or disruption. Uranus hypothetically mentions a great war as a potential event that can affect resources getting reallocated. Uranus means that the mines will remain in operation, however, reaching an agreement is essential to ensure a stable and reliable supply. Uranus concern lies in the fact that the world, as a collective, tends to think short-term, raising the question: *"The big question is how to truly be long-term"*. Uranus emphasizes that Earth's natural resources are finite, and until other planets are explored, Earth remains the sole source.

Purchasing regulations from governments as tariffs and export bans is the source of the world market being dependent on certain relationships. Haumea brings up the trade war between China and USA and witness of the need for an export license to be able to export gallium, germanium and antinomy to the USA. According to Haumea, this is a consequence of USA and China being mutual dependent on each other for different type of materials and components. Haumea states that USA needs raw material from China, while China needs high-tech products from USA and *"China is using the export restrictions in order to get the higher technology* *from USA"*. Haumea mean that *"China is very good for catching up, but they are not so good at the forefront, the technology forefront"* and therefore they are relying on USA for new technology. On the other hand, Haumea does not see this as a major risk at the moment since *"as long as you have the good trade it is not a big deal, but probably you need some kind of bureaucratic procedure"*.

Connecting to the power source of network structure and firm position, an area has been identified by several interviewees as a critical zone regarding forced labor and sustainability, the Uyghur region in China. The area is said to use forced labour and modern slavery and being 100% powered by coal, which is supported by an investigating article about the region written by Crawford and Murphy (2023). Venus highlights the importance of not sourcing from the Uyghur region, as a result from customer requests. Companies actively avoids the area, but due to the network structure it can be challenging to succeed. Venus mean that the firm "can not be sure that our suppliers have left the Uyghur region", which is due to the network structure and the inability to control others due to the firm position. Venus states that the Uyghur region is the main problem in China, but it is difficult to ensure that materials do not flow through it and that suppliers really have left the region. According to Jupiter, sourcing is not being conducted from the Uyghur region. Uranus claim that the Uyghur region is a consequence of not putting any requirements on China regarding labor: "I think that should have been done much earlier - carrying out inspections instead of turning a blind eye" (Uranus, April 2025).

# 6

# Discussion

This chapter critically interprets and integrates the findings in relation to the theoretical frameworks and existing literature. The first section discusses the structure and visibility of the upstream supply chain, and also discusses common themes for the four raw materials. The second section discusses the dependencies and potential risks that follows in a micro, meso and macro system level perspective.

## 6.1 Understanding the Structure and Visibility of the Upstream Supply Chain for Semiconductors

This section will discuss the findings from the supply chain mapping of the four raw materials through the lens of theory, with the aim of trying to explain the observations. This discussion highlights the complexity of the supply network, but also the dependencies that exist within it. This section further tries to explain it with the first research question in mind.

### 6.1.1 Common Themes Across the Four Materials

Across all materials, one of the most recurring pattern is the centrality and concentration of China in either extraction, refining, or both. As brought up in the literature of RDT and network-level power theory by for instance Pfeffer and Salancik (2003) and Pfeffer (1981), actors who control critical resources possess an upper hand and leverage over others. China's dominance is not necessarily based on holding the largest reserves and mines in each case, but on decades of strategic investment in the necessary infrastructure to be able to refine the critical materials the market needs today. Investments that had led to the rest of the world being reliant on China, allowing them to more or less dictate large parts of the upstream supply chain.

From the perspective of power asymmetry concepts from Pazirandeh and Norrman (2014), where control over bottleneck capabilities, which in this case would include processing and state owned refinery infrastructure held by for instance Chinese state owned firms, enables China to hold a dominant power position, especially for at least antimony, germanium, and gallium. For other actors far away from the upstream value chain, such as the reference company and their close suppliers, this creates dependencies that are difficult to manage due to both low substitutability and high information asymmetry. Being so distant from the upstream makes it difficult to change power positions without having clear visibility or close relationships.

### 6.1.2 Material-Specific Supply Chain Dynamics

**High-purity quartz** has a more diversified supply base compared to the other materials, with key sources primarily located in USA. Information on high-purity quartz was comparatively to the other materials easier to find and verify. The more traceable structure for HPQ-companies potentially allows firms to better manage risks, aligning with Peters (2024) view on visibility as a resilience enabler. Moreover, it was found that some companies and suppliers are partially owned or integrated into other's networks, which reflects strategic alliance structures in the HPQ supply chain.

**Gallium** and its supply chain shows a clear structural split where China dominates the low-grade refining capabilities, but lacks the high-grade ones. Instead, Japan and the EU hold those capabilities. Although, the issue is that to obtain high-grade, gallium must first be refined into low-grade. In a way, this reflects the specialization discussed in multi-tier supply chain theory by for instance Mena et al. (2013), and reveals how some countries may dominate some important nodes, but not the entire flow. In line with the findings and the observation from for instance interviewee Haumea, that China imports high-grade, reflects interdependence and not only dependence. China also depends on other countries to manufacture high-end technology. Even though China has a near monopoly on low-grade gallium, this power position could lead to a lock-in for China if they decide not to supply, since the necessary high-grade is possessed by others. Hence, it could be viewed as an interdependent power position.

**Antimony's** supply chain is the most geopolitically constrained one, with nearly all core actors located in China, or Chinese owned abroad, such as in Canada and Tajikistan. Mercury's observation of antimony that "China is everywhere" strongly reinforce these findings. In the context of RDT, this reflects a asymmetric relationship, where buyers are very dependent on a single country for supply. Furthermore, the recent export bans of antimony to USA reinforce the power position of China and emphasize the risk of politicization of these dependencies, as implied by McNamara and Newman (2020) on global disruptions.

**Germanium**, in similarity with gallium and antimony, is a by-product, which complicates the traceability. In order to ensure a more certain mapping, Mars suggested to apply a geological perspective, analyzing the rocks from which germanium can be found. Hence, the mapped mines from zinc might not be totally accurate, but once again China dominates the refining. However, alternative supply chain paths are under development (STL, 2025; Umicore, 2024b, 2025), which shows attempts from the EU to reduce dependency on Asia and build more resiliency around germanium. Such partnerships as Umicore seeks, reflects proactive risk management of interdependencies (Vicente, 2024). Still, these projects takes time and until then, dependencies remains. Also, sourcing exclusively from regions affected by conflict, such as the Democratic Republic of Congo, presents new potential risks, as it may give rise to new and unforeseen dependencies which are not investigated in this study. However, that particular region was not further analyzed in this thesis, but it shows a potential weakness in the Strategic Projects of EU for ensuring critical raw materials in Europe.

### 6.1.3 Visibility in the Supply Chain

Visibility, or the lack thereof, came forward as a key issue in the study. Despite the growing attention to critical raw materials and the effects that prior pandemic disruption had on semiconductors, most companies lack knowledge beyond their immediate suppliers. It did not seem as a high interest and motivation among the interviewees to actually map or be well aware of the network in a different way, even though it was highlighted as quite important, especially after the COVID pandemic consequences (King et al., 2021). Short-term over long-term thinking seemed to be the way of working. As shown in the work of Deloitte (2021) highlighting lack of visibility beyond first tiers, firms seem to face a trade-off between resource intensity and strategic clarity. This was reinforced in the interviews, for instance by Neptune who said that *"we have to balance effort and gain of investigating the upstream supply chain"*. Also, Jupiter pointed out the limited interest in these efforts, expressing that they cannot take on the responsibilities of their suppliers, reflecting a mindset of shifting the burden onto others.

Aelker et al. (2013) highlighted that to handle complexity, transparency is needed. It became clear that transparency is minimal or nonexistent in the semiconductor supply chain. On the other hand, when discussing transparency and visibility, some interviewees mentioned that giving away its supplier list would be to give away business secrets. If one customer and supplier has a stable and long-term relationship, hints could instead be leaved to customers who seek that information, which leaves room to own interpretations rather than true information of supply chain data. Antares mentioned this in the first round interviews and meant that suppliers could sometimes give hints of which country they source from or the first letter of a supplier, but that full names rarely comes out. Hence, it becomes difficult to verify to full certainty. The same thing became evident in the second round interviews where interviewees never told directly which suppliers were present in their network, but rather gave hints in the form of "it looks about right".

Furthermore, one could also argue that even though transparency is wanted in the semiconductor supply chain, companies are not prone to make any progress for this to happen. This was found to come from several reasons. The main one is that perspective brought forward by Neptune and confirmed by Ceres and Pluto, which involved not wanting to concern customers. Giving away transparency would lead to more concerns and questions from customers, which could potentially harm relationships rather than strengthening them. It is rather understood that trust in your suppliers is the strategy of today, as also discussed by Cho et al. (2017) who emphasize trust-based delegation. However, this leads to supplier dependency. The second reason stems from the reasoning from Alam et al. (2020) and (Deloitte, 2021) about the huge size and difficulty to know everything in the automotive semiconductor supply chain. There are too many threads and links between firms and suppliers to follow up on in order to ensure that the mappings made by companies, and the one by the researchers in this study, is correct. Only a certain amount of visibility can be achieved before it becomes blurry and uncertain.

## 6.2 Dependencies and Their Role in Supply Chain Risks

This section focuses more in deep on RQ2: *What dependence dynamics exist and how do they contribute to the risks in the supply chain for the raw materials?* It interprets the empirical findings across the micro, meso, and macro levels and connects it to existing literature of for instance RDT, power and dependency sources, and supply risk management.

### 6.2.1 Micro-Level Dependencies

The findings show that many firms rely and are dependent on internal structures for identifying and managing supply risks. Strategies such as internal coordination, including quarterly reviews and internal task forces for monitoring risks, are some attempts to compensate for low visibility outside of firms. Having this internal control strategy is one way to reduce dependency by improving resiliency internally, as theory from resource dependency highlight (Pfeffer & Salancik, 2003). However, this strategy becomes more reactive rather than preventive if no external visibility is present.

Motivation also plays a key role in justifying whether dependencies are realized or addressed. Previous disruptions such as the COVID pandemic has been highlighted from the interviews as a difficult period for many firms, suffering from mainly supply shortages, but also highlighted as a wake up call and higher motivation. Despite this past disruption, a few interviewees such as Neptune and Jupiter indicate a low urgency due to the current stability in supply and demand. Thus, it seems that past events are easily forgotten once things go back to normal. Even though it can be found that firms and dependent on operational stability, the statement by Mars becomes powerful, that firms fail to justify long-term thinking and supply risk mitigation unless short-term returns are evident. This also connects to Matsuo (2015) who mean that when managing supply risks, rather than focusing on mitigation strategies, the aim should be to improve the ability to quickly adapt to disruptions once they occur.

Furthermore, the statements from Haumea and Neptune that the origin of materials was never important or that *"we are not freaking out at the moment"*, quoted from Jupiter, shows an inertia that limits upstream awareness. Brand reputation can be a source of power which creates supplier dependency, for example when customers rely on larger, established suppliers. In such cases, the strong market position and reliability of the supplier can lead customers to believe that risks are well managed. However, this feeling of security makes the buyer vulnerable if it is not supported by actual supply chain transparency and relevant information. As a result, customers may underestimate potential vulnerabilities and find themselves exposed when and if disruptions occur. However, customers are sometimes left with the only option of trusting their supplier, since they do not have the leverage for pushing for information. Due to the highly complex supply chain of semiconductors, it is not uncommon that the supplier does not have the desired information. Thus, at the micro level perspective, firms are dependent on their own internal motivation, knowledge sharing, and risk mitigation structures. If not properly developed or maintained, they can create hidden weaknesses that can cause problems if disruptions occur in the future.

### 6.2.2 Meso-Level Dependencies

Power asymmetries appear when firms rely on partners who control critical resources or have non-substitutable capabilities (Caniëls & Gelderman, 2005; Emerson, 1962). The findings show a clear dominance by China in refining capacity especially for gallium, germanium, and antimony. This thus aligns with the theory that when one actor is in control over a key resource or process, dependency increases and bargaining power shifts. Due to inertia in investments, capacity and fixed locations for natural resource it is hard to challenge this type of dependency, but initiatives as the Critical Raw Materials Act by the European Commission is one attempt.

Technological capability is by the researchers considered one important meso-level dynamic and perspective. The inability to substitute or cooperate with suppliers due to quality constraints from one of the actors, as noted by Venus, could potentially create lock-in effects. This view aligns with Pazirandeh and Norrman (2014), highlighting substitutability as one key power indicator. Instead, it became evident that firms rely on long-term and standing supplier relationships for assured quality, which then reduces flexibility in times of potential crisis. Another dependency dynamic related to several power sources is the interdependence between the United States and China. USA relies on China for access to critical raw materials, while China depends on USA for high-level technology. This interdependence exists despite ongoing trade tensions between the two nations. Such interdependence between major global actors can have broader implications for other countries and companies, as it is tied to multiple sources of power and influence within the global supply chain. Therefore, the trade war between USA and China creates a variety of dependency dynamics affecting several actors in the industry.

However, some interviewees mentioned multi-sourcing strategies, and meant that this has been one way of reducing dependence after the pandemic and prior disruptions. This seemed to be a recurring pattern for many, as this allows firms to have a second, or even third, alternative for supply. However, as Neptune admits, this does not eliminate the dependency, especially when all suppliers ultimately rely on the same upstream nodes, similar to the example brought forward by (Bowen & Siegler, 2024). This can be connected to the thought of Neptune, the TSMC effect. Ultimately, the vast majority of companies in the semiconductor supply chain are in one way or another dependent on TSMC for microchips. As highlighted in the first round by one interviewee, if TSMC stops, the automotive stops. This is a dependency that the industry is aware of today, but the concentration of refineries in China seems to not be as well known. Furthermore, the lack of supplier transparency and visibility and reliance on Tier 1 or 2 for crucial information reveals an evident information asymmetry, a classic bottleneck in RDT (Pazirandeh & Norrman, 2014; Peters, 2024). Additionally, Jupiter's stance that *"we should not do the job of our suppliers"* demonstrates a risk transfer mindset, which undermines supply chain resilience.

Also multi-tier supply chain management (MSCM) was seen as a key concept among several ones. As discussed by Mena et al. (2013), MSCM involves identifying, creating and managing relationships beyond the first and direct tier suppliers, which could help in finding hidden dependencies. The findings repeatedly show that more or less everyone have limited visibility into the upstream but also beyond their Tier 1 suppliers. This creates information asymmetry and also inhibits preventive risk management for firms. Although Neptune highlight that central groups monitor sub-suppliers, it is a question of how extensive the mapping is and how far beyond suppliers it extends. This highlights a need for deeper tier transparency, especially as disruptions often originate from suppliers beyond Tier 1.

Lastly, the discussion with Tellus opened up new perspectives on the meso-level. Strategically important businesses like UMS highlight a new dimension when national or regional interests, in this case the EU, preserve and help key businesses through policy, funds or investments. Hence, there exist a different level of meso that are not only firm-specific but also rooted in geopolitical considerations. This public-private interdependence reflects this deeper perspective.

### 6.2.3 Macro-Level Dependencies

Macro-level dependencies often go beyond the direct control of individual firms or networks. For example, export bans, particularly China's export restrictions on gallium, germanium and antimony, shows how political power is used through control over important and critical raw materials. As demonstrated in the findings and supported by Haumea, China uses its leverage and market dominance over global supply chains, aligning with McNamara and Newman (2020) and the view that geopolitical dependencies can reshape supply networks by shifting bargaining positions. However, it was at the same time highlighted from Haumea that the political power used by China might backfire due to their depenency on technology from USA. Additionally, China's introduction of these export restrictions and bans aligns with Emerson (1962) who view dependency as a mechanism that can be intentionally manipulated to either exert control or gain advantages.

The findings further show that economic trends and a changing market are perceived as powerful macro-level sources. These can easily lead investments being misaligned. Interviewee Neptune mean that if it takes 2-3 years to build a factory, the market might have changed until its finalization, which demonstrates a demand side uncertainty. At the same time, Jupiter stated that the demand was stable, which not only contradicts the previous statement but also indicates a misalignment in the understanding of the situation. According to Kleindorfer and Saad (2005), such demand side uncertainty is seen to be a key source of disruption risk. It seems that the dynamic nature of demand in the semiconductor industry creates a mismatch between supply and demand fluctuations which is an insight into how macroeconomic situations can create vulnerability even in light of long-term planning.

Non-financial dependencies also came forward, such as macro-level sustainability and ethical concerns connected to the Uyghur region in China. Venus stated that sourcing decisions are increasingly driven by customer expectations and requests and reputational risks. This shows that social legitimacy is a sort of pressure that influences firm behavior. Schneider and Wallenburg (2012) argue that effective stakeholder management which includes aligning with social expectations, is important long-term competitiveness. This is relevant since sustainability becomes integrated into more and more regulatory frameworks, both from governments, organizations and companies.

### 6.2.4 A Multi-level Dependence and Risk Perspective

Putting it all together with dependencies and potential risks in the micro, meso, and macro system levels, Figure 6.1 was created. In the figure, different risks can be seen that correspond to the different levels.

**Micro** level risks arise mainly from not having the internal coordination and motivation at the firm level to investigate the supply chain and be aware of the network dynamics and dependencies. It became evident that sometimes companies does not want to put down the effort into investigating these topics since it is considered to be the job of the suppliers instead. Following this reasoning, there is therefore a risk of getting blind-spots in the supply chain due to not having the multi-tier visibility beyond your first, direct supplier. If a company simply trust the received information from their Tier 1 supplier there is therefore a risk of falling into an information asymmetry situation. As heard in the interviews, suppliers rarely wants to concern their customers, leading to withheld information. Hence, the information received is not always the accurate version. The following risks to this would be to have a delay in detecting potential risks in the supply chain.

**Meso** level risks arise from mainly the bottleneck in terms of refinery capabilities in China. In the event of a disruption, there is a risk of not having other alternative supplies available, i.e. there is low substitutability in the market. With China controlling more or less the majority of refinery capacity, they have a lot of supplier power against the market and more or less all actors are depending on their export.

Another risk at the meso level could be that if companies tries to diversify their supply chain, going away from having only one direct supplier towards having two, three or maybe four instead, there is a risk that their suppliers sub-suppliers is the same one. To put this into context, the refining capacity seems to be similar to the case where actors started to realize during the pandemic that everyone is relying on TSMC for their supply. Today we know that TSMC is a bottleneck, but not as many seems to be aware of the bottleneck a few steps further upstream, regarding the refineries. In other words, there is a risk of customers having an illusion of diversification, while in reality all supply chains needs to go through certain bottlenecks and source from the same place. The illusion of diversification can lead to a false feeling of security, and leave actors vulnerable for future disruptions.

**Macro** risks arise from mainly two things. Firstly, due to the shifts in politics, economics and supply and demand dynamics in the semiconductor market, investments might be uncertain for many companies. Since it takes time to build up infrastructure, there is a risk of not getting a return on the investment if the market has changed once the infrastructure is in place. Also, the demand might have slowed down or changed during this time. This makes the uncertainty high for actors wanting to put investments in.

Secondly, in the event of a global geopolitical shift or disruption, resources might be allocated across actors in the semiconductor supply chain. Since automotive companies represent a relatively small portion of the market of semiconductors, there might be risk that automotive companies are not prioritized. Thus, strategies to prevent supply shortages needs to be developed in order to not go down the same path as when the pandemic hit, now also with the focus on raw materials.

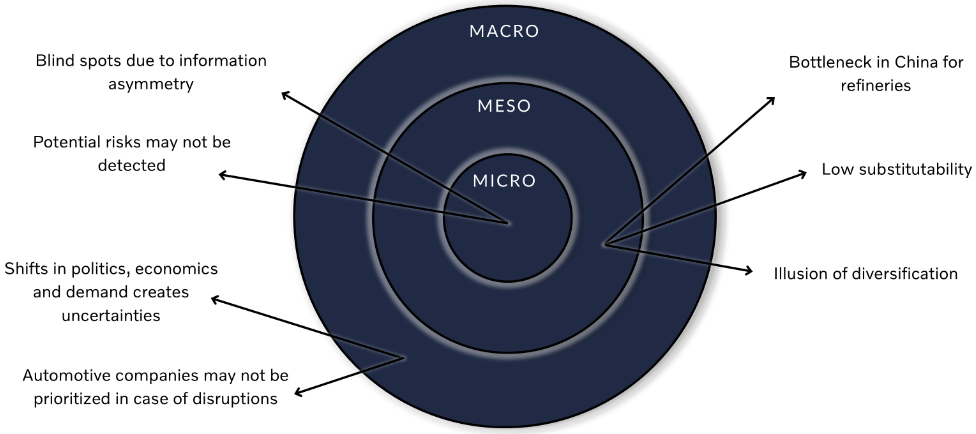


**Figure 6.1:** Potential risks on different dependency levels

# 7

# Conclusion

This study set out to explore the structure and dynamics of the upstream supply chain for four raw materials in the automotive semiconductor industry; gallium, germanium, antimony, and high-purity quartz. By the combination of supply chain mapping with qualitative interview insights from industry actors across different tiers and sectors in the supply network, the research provides a multi-level perspective and understanding of how raw material supply is organized and how dependencies across the whole network contribute to supply risks.

## 7.1 Answering Research Question 1

The first research question considered what the supply chain looks like for these four materials, including core actors, geographical locations and processes. The research findings show that although the downstream supply chain is to some extent rather well understood, the upstream is not. The mapping revealed a high geographical concentration in China for especially refining capabilities, but also for extraction and processing the materials. China is in control of the most global refining capacity for gallium, germanium and antimony, meanwhile high-purity quartz is more widely spread, with most output coming from USA. These dependencies on a few countries, especially China, creates critical bottlenecks and risks that are invisible to downstream companies, including automotive OEMs.

The supply chain mapping done in this study were aimed to be as accurate as possible. However, due to high complexity and a lot of actors involved in the industry, it became increasingly difficult to distinguish what firms should be included and excluded. The mapping therefore resulted in an attempt to catch the core actors present in the supply network, that should be of importance and relevant actors for the reference company. Thus, it could and should be considered as a great snapshot and eye-opener of which core actors exists and where they are present.

## 7.2 Answering Research Question 2

The second research question focused on the types of dependencies that exist and how they contribute to supply risks across different system levels. At the micro level, which considers individual firms, they are internally dependent on their own ability to share information and knowledge and monitor current and upcoming risks. Although the findings reveal that firms are dependent on operational stability, it was found that the internal dependence is perceived as a trade-off between risk preparedness and short-term profitability. Or in other words, if potential gains from risk prevention outweigh the costs of used resources. At the meso level, inter-organizational dependencies were evident, including a heavy reliance on China's concentrated refining capacity, limited substitutability of certain materials and suppliers, and the use of multi-sourcing strategies to mitigate risk. However, multi-sourcing alone may not eliminate the underlying dependency caused by bottlenecks in the control of critical resources. Some firms apply strategic partnerships, multi-tier strategies and dual sourcing to minimize risks and dependencies on several actors, but complete resilience seems difficult to achieve in the semiconductor supply chain due to high specialization and investment costs. Lastly, at the macro level, geopolitical fluctuations, trade restrictions, and global market volatility are the sources of systemic dependencies that affect many in the value chain. China's trade restrictions and resource control, combined with demand fluctuations and regulation shifts, make downstream actors vulnerable.

So, to conclude, this study demonstrates that risks in the automotive semiconductor supply chain of four critical raw materials, are rooted in multi-level dependencies. The findings emphasize the importance of resource dependency theory in understanding how firms react and respond to challenges and power asymmetries. Additionally, multi-tier supply chain management helps in addressing vulnerabilities and dependencies beyond a firm's first or second tier suppliers, but it's rarely enough to identify and reduce all dependencies. To improve visibility and transparency and reduce dependencies in the automotive semiconductor supply chain, firms need to cooperate and coordinate. The EU critical raw materials act is a good start, but requires more effort and reduced permit times to speed up the work. A collaborative effort across all actors in the supply chain is crucial to increase transparency, an approach that may help mitigate potential risks and future disruptions.

## 7.3 Managerial Implications

This study can serve as an eye-opener, encouraging others to investigate hidden dependencies. Not only the dependencies that has an direct influence, but also those embedded in the broader environment that indirectly can have an impact. The report can be viewed as a guide for identifying what to look for and how to trace interconnections. The findings highlight several bottlenecks, however, it is likely that many significant ones remain undiscovered within the scope of this study. Therefore, this report can be seen as a contribution to raising awareness of the importance of exploring such topics, particularly as part of proactive risk prevention strategies. Connecting back to one of the findings of the report, where internal motivation is essential for firms to push others and receive critical information, this study can serve as a tool for motivating firms to take action. Since it highlights the importance of initiating efforts to fully understand entire supply chains, this study can serve as valuable support for those looking to motivate action.

## 7.4 Limitations and Future Research

Significant data limitations were encountered, primarily due to the lack of transparency within the supply chain but also a general unwillingness among key actors to share information. When companies are less transparent or choose not to disclose detailed information, it can be challenging to gather reliable data, especially when the research depends largely on publicly available internet sources. Although a large number of companies were contacted, only a small proportion agreed to participate in the study due to the high resistance of participation. Combined with time constraints, this led to a limited number of interviews during the second round. This also resulted in a high reliance on desktop research and publicly available data, which further constrained the depth of insight. As a result, the findings are shaped by available data and the perspectives of a specific subset of stakeholders, which may not fully represent the diversity of views within the industry.

Future research is therefore encouraged to expand the number and diversity of interviewees and to undertake a more extensive verification of findings through continued market analysis and research. This could involve accessing detailed supplier lists, volumes, market shares, and material flow data, to provide a more comprehensive and validated understanding of upstream supply chain dependencies. A comprehensive mapping of transactions across the global supply chain could enable a better understanding of dependencies related to both raw materials and manufactured components. However, this requires broadening the scope to cover the entire supply chain. This study focused exclusively on the upstream semiconductor supply chain, which limited the ability to capture a full understanding of the market dynamics.

Sustainability is another critical aspect to consider in this field. Particularly due to the energy-intensive processes of mining and refining, but also the transportation required across continents due to the global nature of the supply chain. Furthermore, social sustainability must not be overlooked, as this study has encountered indications of unethical labor practices, including forced labor, within the market. In light of today's increasing emphasis on building a more sustainable future, it is essential that future research incorporates a comprehensive sustainability perspective, addressing both environmental and social dimensions. Additionally, this study has encountered examples of green initiatives as recycling for some of the materials, which should be investigated further to highlight opportunities for change.

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# A

# Appendix 1

## A.1 First Round Interview Guide

- **Starting questions**
  - We are investigating in the elements antimony, germanium, gallium and silica. What do you know about these?
- **Knowledge of supply chain**
  - How deep into the supply chain do you currently have visibility, and where do you see the biggest knowledge gaps?
  - What additional information or transparency would you feel more confident in managing supply chain risks?
  - What do you think is working well in supply chain collaboration today, and where do you see room for improvement?
  - What challenges do you see in the sourcing and availability of critical raw materials like antimony, silicate, germanium, and gallium?
  - Where do you see the biggest risks in the lower tiers of the supply chain, and what kind of support would be most helpful to mitigate them?
- **Knowledge of risks**
  - What are the top three risks currently posing the biggest threat to the semiconductor supply chain, and why?
- **Existing strategies for risks / risk management**
  - How does your organization plan for both foreseeable and unforeseen supply chain risks?
  - Can you share examples of how and if your organization has handled past crisis and what lessons were learned?

  - How are geopolitical and environmental risks influencing the sourcing strategies for semiconductors?

- **Choosing supply chain**
  - How does your company work with suppliers to ensure compliance with environmental regulations and sustainability goals?

- **Ending**
  - How many people within your organization are actively engaged in managing these risks, and how is their work structured?
  - Do you have any recommendations on who to talk to further?

## A.2 Second Round Interview Guide

Second round interview questions were tailored depending on the respondent. Thus, all questions are here included.

- **General Awareness and Knowledge**
  - Are you using Gallium, Germanium, Antimony or High Purity Quartz?
  - Are you aware of where your materials are extracted and refined?
  - How far up the supply chain do you have knowledge?
  - How far up the supply chain do you think others have knowledge?

- **Dependencies**
  - Regarding your supply of these materials, what dependencies do you have or see?
  - What dependencies do you see there is in the market today? Small, medium and large scale?
  - Are you dependent on certain countries or companies of supply?
  - What relations are you dependent on to be stable?
  - Do you have any geographical dependencies?
  - Do you have any relationship-based dependencies? Any key players you cannot function without?
  - How do you get the information (transparency/visibility) you need?

  - What do you see as the major bottleneck in the supply chain of mining operations? Concentrated areas or companies etc?
  - Do you experience that companies are holding back negative or concerning information to customers or suppliers?
  - Is there any risk with sharing negative or concerning information to customers or suppliers?

- **Risks**
  - Is it necessary to investigate in the upstream supply chain?
  - What are you worried about regarding the supply of the materials?
  - Who should be worried about what?
  - (If not worried) What makes you not being worried?
  - What is the worst, most likely, thing to happen right now?
  - What risks do you see regarding your dependencies today?
  - What risks do you see in the coming 5 to 10 (or short-term) years?
  - What risks do you see long-term for the market?
  - Where do you see the biggest risks in the lower tiers of the supply chain?
  - What challenges do you see in the mining sector?
  - Is there any challenge that can be turned into opportunities in this fast-changing environment regarding the supply of these materials?
- **Scenarios**
  - What happens if the supply of one or more of the raw materials would be stopped for supply?
  - What happens if another disruption event would occur that would lead to higher demand than supply? What actions would be needed to prevent this?
  - What emergency plans have been constructed since the uncertainties around China's export started in 2023?
  - How is the transformation from a risk to a crisis defined for you? When is the situation considered a crisis?
- **Strategies needed**

- What kind of initiatives do you think would be needed from companies to secure their supply of critical raw materials?
- What do you as a company do to mitigate the risks of supply?
- Do you feel that your company gets the information needed to put up efficient strategies?
- Do you feel that you have strategies that protects you from potential risks?
- What strategies do you apply or use for scenarios like gallium or antimony where the concentration is so high?

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