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Achieving Sustainability in Complex Multi-Tier Supply Chains:

The Role of Supply Chain Visibility and Transparency in Responsible Sourcing of Critical Minerals

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Abstract

There is growing pressure from stakeholders on global corporations to ensure the sustainability of their products throughout the supply chain. At the same time, due to the high complexity and dynamism of supply chains, companies often do not know what actors operate in their supply chains beyond direct suppliers. Supply chain visibility (SCV) and transparency (SCT) are crucial for ensuring responsible sourcing practices. However, achieving SCV and SCT poses challenges due to systemic issues in supply chains. This pressure is particularly high for mineral supply chains that are known for issues linked to the environment and human rights. At the same time, these supply chains are inherently complex and dynamic, leading to a lack of visibility for companies regarding the actors involved. This study highlights the challenges and current practices in attaining SCV and SCT in minerals supply chains, as well as the potential solutions and emerging technologies that can drive their development. The present study employs two theoretical frameworks to analyze the process of achieving visibility and transparency in multi-tier supply chains: multi-tier supply chain (MTSC) theory and complex adaptive systems (CAS) theory. These frameworks are a particularly suitable lens for this analysis because they acknowledge and explain the complexity, dynamics, and multiple tiers found in mineral supply chains. The research utilizes a qualitative study approach, gathering empirical data through participant observation, 7 semi-structured expert interviews, and analyzing 62 practitioner documents (reports, articles, websites, webinars) using qualitative content analysis in NVivo. This study includes perspectives of actors from different parts of supply chains from upstream to downstream, as well as technology providers. The results emphasize the importance of a systematic approach to SSCM and the need for new approaches and digital technologies to enhance SCV and SCT and enable data collection from complex, dynamic supply chain systems.

Keywords: critical minerals, supply chain transparency, supply chain visibility, sustainable supply chain management, traceability

Executive Summary

For many global companies, the significant environmental and social impacts of their activities occur in their supply chains. Supply chain visibility (SCV) is crucial for ensuring the high sustainability performance of actors in the supply chain, as without it companies are limited to their direct suppliers and unable to manage risks and impacts across their entire supply chains. Supply chain transparency (SCT) enables companies to demonstrate high sustainability standards and responsible sourcing practices for materials used in their products to their stakeholders. However, achieving SCV and SCT poses challenges due to systemic issues in supply chains. The critical minerals supply chain presents a unique set of sustainability challenges due to the minerals' essential role in modern technologies and the transition to a low-carbon economy. These minerals are often associated with regions where human rights violations and negative environmental impacts are prevalent. However, companies face challenges such as limited knowledge about supply chain actors, lack of contractual relationships beyond direct suppliers, and inadequate mechanisms to influence suppliers and sub-suppliers. Enhancing SCV and SCT are key priorities for companies striving to improve supply chain sustainability.

The **objective** of this research is to examine the drivers, barriers, necessary conditions, available technologies, and the benefits and limitations of SCV and SCT for sustainable supply chain management (SSCM). Specifically focusing on minerals supply chains known for human rights violations and negative environmental impacts, this study explores how SCV and SCT are implemented in these supply chains. The present study employs two theoretical frameworks to analyze the process of achieving sustainability goals in multi-tier supply chains: **multi-tier supply chain (MTSC) theory and complex adaptive systems (CAS) theory**. MTSC theory provides a framework for understanding the main factors and approaches to sustainable supply chain management, while CAS theory enables a deeper understanding of the behavior of supply chains and how sustainability interventions can influence their dynamics. Thus, these two theories are well suited to understand and explain the complex reality in mineral supply chains where companies face limited visibility.

This study employs a qualitative **research design** incorporating elements of ethnography and case study methodologies. The primary sources of data for the study consist of 47 published documents from 16 companies operating in the automotive, electronics, consumer goods, and industrial goods industries. Additionally, 5 webinars and 10 reports from industry associations and consultancies were utilized. The perspectives of practitioners (professionals working in companies along mineral supply chains) were gathered through 7 interviews. The main approach to the data collection and analysis is multi-perspective, and research includes perspectives of different actors of supply chains (downstream, midstream, upstream), third parties (industry associations, technology providers), and different industries (automotive, consumer electronics, industrial solutions). The data underwent a comprehensive analysis process, starting with a systematic review using qualitative content analysis in NVivo. This was followed by an in-depth examination of the identified themes.

The **research results** show that the current level of SCV and SCT in minerals supply chains is still very low. The current practices adopted by companies fall short in addressing the complexity of supply chains, hindering the achievement of SCV and, consequently, impeding companies from effectively responding to the pressures from stakeholders and regulators for supply chain transparency SCT. While there are several initiatives underway to enhance SCV and SCT through the exploration of new approaches and digital tools, these initiatives are still in the early stages of development. Nevertheless, it is crucial to persist in testing and refining

these solutions, as they hold the potential for driving meaningful progress. Increased attention and investment in this field are needed to promote advancements in SCV and SCT practices.

The main research questions explored in this study include:

RQ1: what role do SC visibility and transparency play in SSCM process

RQ2: what approaches do large multi-national companies implement to achieve SC visibility and SC transparency and what different factors influence company's choice of approaches to SCV and SCT

RQ3: what are key challenges and success factors in the process of establishing SCV and SCT

The **first research question** can be answered as follows: SCV is vital for achieving SSCM goals and making a positive impact, though it is not the ultimate objective. However, it can enable realizing other sustainability goals like decarbonization. SCV enables companies to pinpoint hotspots and take targeted actions to improve sustainability performance. SCT requires SCV as companies aim to evaluate possible risks and gain control over them before becoming transparent. Both SCV and SCT aim to reduce supply chain complexity, enhance connectivity, and minimize sustainability risks. In an unpredictable and evolving environment, visibility is crucial for making timely strategic decisions and can become a company's competitive advantage.

The **second research question** can be answered as follows: current practices fall short of achieving supply chain visibility in minerals supply chains. Indirect approaches are commonly used, relying on the willingness of suppliers to transmit requirements throughout the supply chain and ensure compliance of their sub-suppliers. Regulatory and stakeholder pressure is increasing, pushing companies to change their SSCM practices. Existing tools for SCV and SCT are limited, lacking coverage of the entire supply chain and required indicators from regulations and stakeholders, and failing to capture supply chain dynamism and complexity. Emerging digital technologies hold promise in elevating SCV and SCT to new levels allowing real-time visibility of origin, chain of custody, and sustainability indicators. However, these technologies also depend on supply chain actors' willingness to cooperate, establish trust, and embrace change. There is a growing need for collaborative exploration of digital technologies for SCV and SCT, involving supply chain actors and third parties to ensure scalability and applicability to multi-mineral supply chains.

The **third research question** can be answered as follows: achieving SCV and SCT is a complex undertaking that presents various challenges for companies operating in global supply chains, including the difficulty of involving sub-suppliers in SSCM practices, information imbalances and protection over commercially sensible information in supply chains, heightened scrutiny and pressure from stakeholders resulting from transparency, the high costs of changes and its distribution among supply chain actors, the lack of robust business cases outlining the advantages of SCV and SCT, complexity, dynamism, and self-organized nature of supply chains. The key success factor and one of the biggest challenges is collaboration among actors in supply chains. Implementation of SCV and SCT practices requires collective agreement on operational mechanisms, cost sharing, market functioning, and standards, among other parameters. Supply chains are already changing, and many factors will continue to drive the system to the new states, where SCV and SCT may become compulsory characteristics of the supply chain.

This thesis has the following **contributions to research and practice**. Firstly, it provides a comprehensive overview of the current state of SCV and SCT practices in minerals supply chains. The application of MTSC and CAS theories enhances the understanding of supply chain complexity and its impact on SCV and SCT feasibility. The identified challenges through practitioner interviews highlight key areas that need attention. Secondly, the research emphasizes several underexplored areas like the role of midstream and upstream actors in SCV/SCT implementation, success factors and conditions for effective multi-stakeholder collaboration for SCV/SCT, and technology integration in the existing SSCM practices. From a practical standpoint, the research provides insights into SCV and SCT implementation, identifies critical elements to consider during the implementation process, and highlights the challenges faced by companies that have already started this journey.

In conclusion, the implementation of SCV and SCT is crucial for achieving sustainability goals and meeting stakeholder demands for responsible practices in the supply chain. Although challenges exist and best practices are still emerging, the landscape is evolving with collaborative projects dedicated to addressing these challenges. Active participation in these initiatives enables companies to contribute to the advancement of SCV and SCT practices. While the path to SCV and SCT is complex, ongoing collaborations and projects serve as catalysts for progress, guiding supply chains toward sustainability. As more companies join these efforts, the momentum for responsible practices will grow, creating a future where SCV and SCT are integral to a responsible and sustainable supply chain.

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Abbreviations

GHG - greenhouse gas

SC – supply chain

SCT – supply chain transparency

SCV – supply chain visibility

SSCM – sustainable supply chain management

1. Introduction

For many companies the significant environmental and social impacts of their activities, for example, greenhouse gas (GHG) emissions, poor working conditions, and human rights violations occur outside their organizational boundaries. As an example, on average 5,5 more emissions occur in the supply chain than from direct activities of the business (CDP, 2019). Deloitte provides another estimation: based on their study, more than 70% of companies' carbon footprint comes from supply chains (Deloitte, n.d.). In many cases, companies have ambitious sustainability goals, but they are not cascading these goals down to their suppliers and overall engagement with suppliers' sustainability performance remains low.

In the recent decade sustainable supply chain management (SSCM) was under close public attention due to human rights violations, social and environmental disasters, growing supply chain disruptions due to extreme weather conditions, pandemics, geopolitical conflicts, etc. (Ernst & Young, 2022; Montecchi et al., 2021). Nowadays, companies must navigate in situations of extreme changes and disruptions ensuring supply chain resilience and continuity of their business (Correll & Betts, 2022). At the same time, big multinational companies have multi-tier supply chains with a high number of actors with complex interconnections operating in different contexts and geographies. This makes supply chain management challenging, especially in the situation when a company does not have direct contact with sub-suppliers and in many cases does not even know these sub-suppliers (Ernst & Young, 2022; Fraser et al., 2020; Hofstetter & Grimm, 2019; Kogg & Heldt, 2022). Most sub-suppliers operate in "emerging markets where the responsibilities and control mechanisms of companies are limited or restricted", making them "prone to sustainability-related risks and uncertainties" (Ebinger & Omondi, 2020, p.2). No matter if the company has or does not have the capability or resources to assure the sustainability of its supply chain, different stakeholders expect that the company will take responsibility for the violations of sustainability standards in any part of the supply chain (Acquier et al., 2017; Hofstetter & Grimm, 2019). Moreover, there is constantly growing pressure on companies from stakeholders, such as investors, consumers, NGOs, policymakers, and employees to ensure sustainability compliance across the supply chains (Correll & Betts, 2022; Ernst & Young, 2022).

The challenge of supply chain sustainability is particularly acute for the critical minerals supply chain, as they are essential for modern life as a part of all consumer and industrial electronics, and moreover, minerals are crucial for the transition to a low-carbon economy: electric transportation, renewable energy production, energy storage, etc. "A critical mineral is a metallic or non-metallic element that has two characteristics: it is essential for the functioning of modern technologies, economies or national security and there is a risk that its supply chains could be disrupted" (Geoscience Australia, 2022). Many minerals are considered critical, but in this study, critical minerals will mostly refer to gold, tin, tungsten, tantalum (also called 3TG or conflict minerals), cobalt, nickel, lithium, and magnesium (Geoscience Australia, 2022; IEA, 2021; USGS, 2022). Up to 70% of the world's production of critical minerals can occur in regions with high risks of human rights violations, including forced, child, and low-paid labor, and negative impacts to the environment such as air and water pollution, deforestation, etc. (IEA, 2021).

To achieve sustainability goals companies need to find effective strategies and tools to transmit their standards for environmental, social, and governance practices (sustainability standards) across their supply chains (Hofstetter & Grimm, 2019; Kogg & Mont, 2012). However, companies face several challenges such as the lack of holistic knowledge about supply chain actors, lack of contractual relationships with suppliers beyond direct suppliers, and lack of other mechanisms to influence suppliers and sub-suppliers (Hofstetter & Grimm, 2019). An essential

priority for companies is to understand better their supply chains by increasing their visibility (Ernst & Young, 2022). Supply chain visibility (SCV) is defined as a state in which specific information about suppliers and buyers in any tier of the supply chain is available to a company (Schäfer, 2022; Sodhi & Tang, 2019), Some companies go beyond that to provide supply chain transparency (SCT) to their stakeholders, which is defined as the practice of disclosing detailed and accurate information about operations and products, including their origin and sourcing (Bai & Sarkis, 2020; Montecchi et al., 2021).

1.1. Problem definition

Some authors state that SCV and SCT are necessary conditions for effective sustainability risk management in the supply chains and the achievement of sustainability goals in the supply chains in general (Ebinger & Omondi, 2020; Ernst & Young, 2022; Fraser et al., 2020; Hartmann & Moeller, 2014; Montecchi et al., 2021). However, current research remains unclear as to how SCV and SCT can be achieved in complex multi-tier supply chains. Current research views SCV as a condition for and antecedent of SCT and SSCM (Montecchi et al., 2021; Sodhi & Tang, 2019). Considering the complexity and dynamics of multi-tier supply chains and growing stakeholder pressure, it seems plausible that transparency could also be a driver of SCV and SSCM practices in general, and that the relation between the three concepts (SSCM, SCV, SCT) is more complex and nuanced than currently acknowledged. The research problem for the thesis study can, thus, be formulated as how SCV and SCT can be achieved in minerals supply chains, and how companies can use insights on connections between SSCM, SCV, and SCT to accelerate the transition to more sustainable supply chains. Further investigation of tools, challenges, and necessary conditions for SCV and SCT can contribute to the wider implementation of these practices. Also, the decision-making process can be made easier if available strategies for SCV/SCT are explored and their results are formulated.

1.2. Research aim and research questions

The thesis research aims to explore the process of achieving sustainability goals in large multinational companies with complex multi-tier supply chains through increasing visibility and transparency of supply chains. In the focus of this study are critical minerals supply chains, that are known for the non-sustainable practices in the upstream of SC. As minerals are crucial for all electronics products, achievement of sustainability goals across the supply chain is a top priority for many downstream companies. This research will investigate drivers, barriers, necessary conditions, available technologies for SCV/SCT, and their benefits and shortcomings for the SSCM. This will allow to provide necessary knowledge for wider implementation of SCT practices as a part of SSCM in large multinational companies with complex multi-tier supply chains. The following research questions have been formulated to achieve the research aim:

RQ1: what role do SC visibility and transparency play in the SSCM process

RQ2: what approaches do large multi-national companies implement to achieve SC visibility and SC transparency and what different factors influence a company's choice of approaches to SCV and SCT

RQ3: what are key challenges and success factors in the process of establishing SCV and SCT

1.3. Limitations and scope

While this thesis study aims to provide valuable insights into the topic at hand, it is important to acknowledge its limitations. Firstly, the sample size for data collection is limited, comprising

a specific number of expert interviews and practitioner documents. Although efforts were made to ensure diversity in the selection process, the findings may not fully capture the perspectives and experiences of all relevant stakeholders in the field. This study covers only several companies within four industries, where critical minerals are essential parts of the product. In the scope of this research are large multinational companies with multi-tier supply chains of critical minerals (gold, tin, tungsten, tantalum, cobalt, nickel, lithium, and magnesium) in the industrial manufacturing, automotive, electronics, and other consumer goods industries. Secondly, the research is conducted within a specific time frame and resource constraints, which may restrict the depth and breadth of the analysis. The complexity of the topic, involving various dimensions such as organizational, technological, and economic factors, implies that some aspects may not receive exhaustive coverage due to these limitations. Lastly, as with any qualitative research, there is a potential for researcher bias. Despite efforts to remain impartial and objective, personal perspectives and interpretations may influence data analysis and findings. To mitigate this limitation, rigorous data analysis procedures and data triangulation are employed to enhance the credibility and reliability of the research.

1.4. Ethical considerations

The thesis research is conducted independently, ensuring that there are no external influences from individuals or organizations that could impact the research process or its outcomes. This independence allows for unbiased exploration and analysis of the research topic.

In line with ethical considerations, participation in the research was entirely voluntary. Before the interview, all respondents were informed about the research objectives and the interview format. They were given the opportunity to provide informed consent for recording the interview and being named in the research paper. Alternatively, if preferred, interviews can be conducted anonymously. Respondents had the opportunity to review and verify the accuracy of the interview transcripts. These measures ensure the protection of sensitive information and maintain confidentiality throughout the research process, and allowed to maintain data accuracy.

To safeguard the collected data, all information will be stored on a password-protected laptop. This security measure helps prevent unauthorized access and ensures that the data remains confidential and protected. By taking these precautions, the research team upholds the principles of data privacy and confidentiality, adhering to the highest ethical standards in research practices.

2. Background and theoretical framework

2.1. Complex multi-tier supply chains

This study centers around the multi-tier supply chain, which encompasses a complex system comprising a focal company, its numerous suppliers across multiple tiers, and buyers interconnected within the supply chain network (Gong et al., 2021). A focal company is understood as the large, powerful actor that creates and governs the supply chain network to produce goods and services for the end customer. Focal company purchase goods and services from their first-tier suppliers, also called direct suppliers. First-tier suppliers have their own smaller networks of suppliers that can have different numbers of tiers in them. For the focal company, they are sub-suppliers or indirect suppliers, also called middle-tier or low-tier suppliers depending on their distance from the focal company in the supply network. Other common terms to describe supply chains are downstream (focal company and its buyers), midstream (first- and middle-tier suppliers), and upstream (low-tier suppliers, raw materials producers) companies. All suppliers that are actively managed by a buyer are called a supply base (Choi & Krause, 2006).

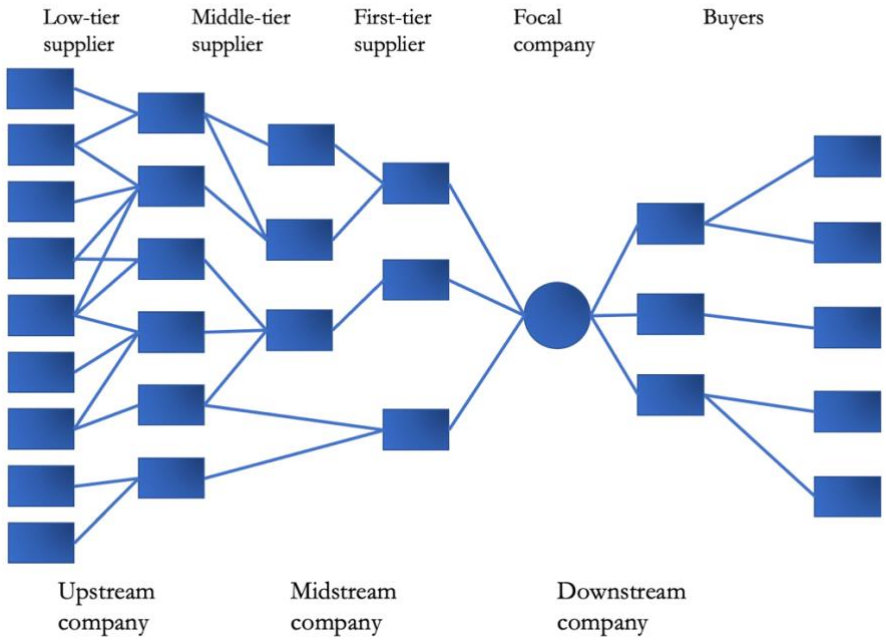

Figure 2-1. Simplified scheme of multi-tier supply chain

Source: own illustration

Several different authors provide frameworks and theories to explain the complexity of SSCM that influence the overall success of new practices implementation throughout the supply chain (Acquier et al., 2017; Choi & Krause, 2006; Cox, 2001; Kogg & Mont, 2012; Ponte & Sturgeon, 2014). Multi-tier supply chains often have high dynamics, where "multiple sourcing and frequent exchanges of sub-suppliers occur" which leads to the lack of visibility and knowledge about actors in supply chains and the relationships between them (Hofstetter & Grimm, 2019, p.539). The level of complexity is characterized by the number of suppliers, their diversity, and their inter-relationships (Choi & Krause, 2006, p.637). Globalization, increased specialization, and outsourcing are the main drivers of growing supply chain complexity (Ebinger & Omondi, 2020).

Focal companies can become aware of the actual level of supply chain complexity if they are systematically explored. In many cases, focal companies have a limited understanding of their supply chains. Supply chain complexity leads to the lack of information or its low accuracy that poses threats to the focal company's risk management (Fraser et al., 2020). Another layer of complexity in the buyer and supplier interaction in the supply chain comes from a power balance perspective. Cox's power matrix explains four different scenarios: buyer dominance, supplier dominance, independence, and interdependence, and justifies that both parties aim to create conditions for their dominance (Cox, 2001). The application of the power matrix to SSCM was investigated by Kogg & Mont (Kogg & Mont, 2012). Based on the data gathered during 2 independent studies of Swedish companies, they conclude that collaboration strategies for increased sustainability of supply chains can be possible only in certain situations of power balance: supplier dependency or mutual dependency. A focal company can use strategies to increase its relative power through sourcing choices (supplier selection or deselection) or adapt its SSCM practices according to the existing power balance (Kogg & Mont, 2012).

Supply chain complexity is often viewed as a barrier to effective supply chain governance, but at the same time strategy to reduce the complexity of supply chains may not be always beneficial: it can lead to decreased transaction costs and better responsiveness of suppliers, but consequently have increased supply risks and lower innovation. Supply risks are higher in both cases of high complexity (lack of control mechanisms) and low complexity (putting all eggs in one basket can make the supply chain more vulnerable to negative events and disruptions). And the level of innovation among suppliers is big if there are many diverse actors with a high level of autonomy in the supply base (Choi & Krause, 2006).

No matter if the company has or does not have the capability or resources to assure the sustainability of its supply chain, different stakeholders expect that the company will take responsibility for the violations of sustainability standards that occur in any part of the supply chain (Acquier et al., 2017; Ebinger & Omondi, 2020; Hofstetter & Grimm, 2019). This phenomenon is called by some authors "a chain liability effect in multitier supply chains". External stakeholders may not have a good understanding if a company has the resources or capabilities to take responsibility for its supply chains. At the same time, it is an easy solution to blame one big powerful company instead of a big number of not well-known upstream suppliers, so the focal company plays the role of a "scapegoat" for the stakeholders frustrated by occurred violations (Hartmann & Moeller, 2014).

2.2. Policy context

The legislation of supply chains is constantly developing aiming to make the downstream companies carry more responsibility for their supply chains through mandatory supply chain due diligence requirements. Existing and upcoming regulations and frameworks can be divided into three types:

- Policies covering due diligence obligations for specific sectors or product groups, examples include the regulation on conflict minerals (EU regulation 2017/821) and the battery regulation (Proposal No 2019/1020).
- Policies covering due diligence obligations for specific types of companies (by size or by location), examples include the EU sustainability reporting directive (CSRD) and the German Supply chain due diligence act.
- Non-binding frameworks and recommendations, examples include The United Nations (UN) Guiding Principles on Business and Human Rights and OECD sector-specific due diligence guidances for agriculture, garment and footwear, extractive industries, and responsible supply chains of minerals from conflict-affected and high-risk areas.

Supply chain due diligence was mostly guided by non-binding recommendations and guidelines in the last decade, but in the last few years, new policies were developed to make supply chain due diligence obligatory. As an example, CSRD (adopted in 2022) introduces "binding obligations for large firms to identify, prevent and minimize adverse human rights and environmental impacts in supply chains" (World Economic Forum, 2022, p.7). According to CSRD, companies will have to disclose information on human rights, environmental impact, and governance in their management reports covering their value chain. This includes identification and reporting on the adverse impacts, and actions taken to monitor, prevent, mitigate, remediate, or bring an end to those impacts (Accountancy Europe, n.d.; Circularise, 2022; EU Directive 2021/0104, 2022). This will be a significant driver for companies to increase the visibility and transparency of their supply chains and expand SSCM practices to avoid accusations of inaction. Another example is Battery Regulation (is expected to be adopted in 2023), which states that battery producers should comply with the supply chain due diligence obligations, including establishing a chain of custody or traceability system or the identification of upstream actors in the supply chain (*Proposal No 2019/1020*, 2020). This kind of policy forces companies to introduce new technologies that enable product traceability in a trusted and secure manner.

2.3. Theoretical framework

Multi-tier supply chain theory (MTSC) and complex adaptive systems (CAS) are used as a theoretical foundation for the research. MTSC views SSCM as a linear process, where specific factors influence the choice of strategy. CAS shows that supply chains are complex non-linear systems where results are difficult to predict. MTSC theory offers a clear and uncomplicated framework for comprehending the fundamental factors and approaches to managing sustainable supply chains. However, the MTSC theory has its limitations, especially when it comes to comprehending the intricacy and dynamic nature of multi-tier supply chains. On the other hand, the CAS theory acknowledges that supply chains are intricate adaptive systems that show spontaneous behavior, self-organization, and adaptability to changing circumstances. This approach provides a more profound understanding of supply chain behavior and how sustainability interventions can impact their dynamics. In this study, both theories are applied to highlight different aspects of supply chains that have a significant influence on the level of SCV and SCT development in the given supply chains.

Multi-tier supply chains theory

Multi-tier supply chain theory proposed by Tachizawa and Wong is used in the analysis of strategies that large multinational companies implement to achieve SCV and SCT and factors that influence their choice of approaches to SCV and SCT (RQ2). According to this theory, a multi-tier supply chain includes multiple levels of suppliers and buyers, each with its distinct objectives, constraints, and relationships. Tachizawa and Wong expand upon the traditional concept of a supply chain to account for the complex relationships between multiple tiers of suppliers and buyers and explore what practices and governance mechanisms companies use for managing their low-tier suppliers, and what factors influence their decision.

Tachizawa and Wong identify four types of governance mechanisms in sub-supplier management: direct, indirect, work with third party, and don't bother. An overview of four governance mechanisms and relevant practices is shown in Table 2-1. The first step towards addressing RQ2 involves identifying the four types of governance mechanisms that are currently implemented in practical settings within minerals supply chains.

Table 2-1. Four types of governance mechanisms in sub-supplier management

Type	Characteristics
Direct	Focal companies possess the capability to establish a direct connection with lower-tier suppliers and oversee, regulate, and cooperate with them to improve their environmental or social performance, bypassing first-tier suppliers.
Indirect	Indirect contact with lower-tier suppliers is typically established through intermediary first-tier suppliers, who undertake the monitoring and collaboration efforts with these suppliers.
Work with third party	Focal firms engage in partnerships or assign duties to external organizations to develop sustainability criteria, enforce industry self-governance, adopt voluntary guidelines, etc.
Don't bother	Companies concentrate on their first-tier suppliers and do not possess any knowledge about their lower-tier suppliers, nor do they intend to exert any influence over them

Source: (Gong et al., 2021; Tachizawa & Wong, 2014, p.651-652, 656)

As Tachizawa and Wong state that many factors influence the choice of governance mechanisms, including power, stakeholder pressure, material criticality, industry, dependency, distance, and knowledge resources (Gong et al., 2021; Tachizawa & Wong, 2014), these factors can be evaluated in the analysis of chosen approaches to SCV / SCT. An overview of four governance mechanisms is shown in Table 2-2. For different products (electric vehicles, consumer electronics, industrial electronics, etc.) these factors can have different significance and thus lead to different choices of strategies.

Table 2-2. Factors influencing the choice of governance mechanisms in sub-supplier management

Factor	Description of the factor
Power	The ability of an organization to influence the actions of other members of the supply chain. The greater the power held by the focal company, the more feasible it is to influence suppliers and, subsequently, sub-suppliers in compliance with sustainability standards
Stakeholder pressure	The level of demand for a specific company's behavior from different stakeholders. The greater the level of stakeholder pressure, the more likely companies are to allocate resources towards the supply chain in question and endeavor to assert direct control over their sub-suppliers
Material criticality	The impact that certain materials have on the final product sustainability. Highly critical materials may require lead firms to establish direct links with lower-tier suppliers, while materials with low criticality may result in a more indirect approach to lower-tier suppliers
Industry	The industry context can affect the investment in environmental and social practices, the effectiveness of sustainability standards, and the intensity of institutional pressure for performance improvement
Distance	The physical, geographical, and cultural separation between different tiers of suppliers in the supply chain network. The distance factor can affect the level of control that the focal company has over lower-tier suppliers, the effectiveness of communication between different tiers, and the level of coordination between suppliers.
Dependency	The level of dependence that a company has on its suppliers, can be influenced by various factors such as the availability of alternative suppliers, switching costs, and supplier concentration. Companies with high dependence on their suppliers are more vulnerable to disruptions in the supply chain but at the same time have less leverage to drive sustainability standards cascading over the supply chain
Knowledge resources	The insufficiency of knowledge and technical expertise is a significant motivator for leading firms to cooperate with external entities to create and execute sustainable measures within the supply chain. Companies with limited knowledge resources may choose to implement sustainable practices only after established firms, thereby reducing their risk exposure.

Source: (Tachizawa & Wong, 2014)

The multi-tier supply chain theory by Tachizawa and Wong can contribute to the study of SCV and SCT by highlighting the importance of understanding the relationships and dependencies

between different tiers of suppliers, the factors that influence SSCM practices, and the ability to establish SCV and SCT within different approaches to the supply chain governance.

Complex adaptive systems theory (CAS)

Complex adaptive systems theory has been applied by several authors in sustainable supply chain research as it allows to view supply chains as highly dynamic and complex systems that cannot be predicted or controlled (Carter et al., 2015; Choi et al., 2001; Touboulic et al., 2018). CAS theory thereby challenges the implicit assumption in much of existing SSCM research that the focal company can unilaterally control and manage sustainability issues.

CAS theory offers a valuable framework for understanding SSCM challenges by emphasizing the dynamic, non-linear, and emergent behavior of supply chain systems. CAS theory views a supply chain system as a network of interconnected agents that adapt to changing internal and external environments, exhibiting self-organization. This approach highlights the importance of understanding the system's complexity, interdependencies, and interactions among its agents, as well as the potential for unintended consequences and the emergence of new behavior such as increased SCV and SCT. One of the theory's implications is that the implementation of new technologies, including those connected with SCV and SCT, in the supply chain context can be challenging due to the inherent complexity of the system. As a result, predicting the outcomes of such interventions can be difficult (Bai & Sarkis, 2020).

CAS theory has been applied to the analysis of different aspects of SSCM in several academic articles. In Choi's (2001) article, the application of CAS theory to supply network management is explored. Choi argues that traditional approaches to supply chain management has been ineffective in dealing with the complexity and uncertainty of supply networks and proposes a new model for supply network management that incorporates CAS principles and emphasizes the importance of collaboration, information sharing, and trust. In Touboulic's (2018) article, the author applies CAS theory to the problem of reducing carbon emissions in a food supply network. Touboulic argues that traditional approaches to carbon reduction have been ineffective because they fail to account for the complexity and interconnectedness of the food supply network. The author proposes a new approach that incorporates CAS principles, including emergent behavior and self-organization, to create a more effective and sustainable system.

In summary, MTSC theory focuses on understanding the inter-organizational relationships and dependencies across multiple tiers of the supply chain, as well as the factors that influence these relationships. The theory emphasizes the importance of managing relationships with lower-tier suppliers in order to establish SCV and SCT and evaluates the choice of governance mechanisms based on factors influencing the system. In contrast, the CAS theory views supply chains as dynamic and evolving systems with emergent properties that arise from the interactions and behaviors of the individual actors within the system. The theory offers insights into the dynamics and behaviors of the system as a whole. This approach focuses on understanding the self-organizing and adaptive properties of supply chains, as well as the feedback mechanisms and non-linear relationships that can influence how the system reacts to the increased level of SCV and SCT. While there may be some overlap between these two approaches, they offer different perspectives on understanding and managing visibility and transparency in supply chains.

3. Literature review

The literature review is focused on three key concepts in the sustainable supply chain research field: sustainable supply chain management (SSCM), supply chain visibility (SCV), and supply chain transparency (SCT). The literature review aims to provide an overview of the current state of knowledge on these concepts and formulate propositions on the relationships between them. For each concept definitions, key characteristics, drivers, barriers, and approaches are synthesized.

3.1. Sustainable supply chain management

According to Smith, SSCM is "the proper management of related environmental, social, and economic impacts in constructing and maintaining effective and efficient global supply chains" (Smith, 2015). It includes the management of direct suppliers and sub-suppliers (Hofstetter & Grimm, 2019). SSCM is based on interactions between SC actors that aim to eliminate sustainability violations like environmental damage, human rights abuses, law infringement, corruption, and other kinds of non-responsible business behavior, and at the same time ensure the profitability of the business (Ebinger & Omondi, 2020).

According to the study conducted by Ernst & Young among 525 large corporations, key drivers for the development of SSCM are cost savings (61%), compliance with regulation (51%), and pressure from partners/suppliers (41%) (Ernst & Young, 2022). MIT's study on supply chain sustainability highlights that the biggest pressure to improve SSCM comes from investors, customers, and the company's executives. Even if the regulatory demands for SSCM are low in some markets, high pressure from end customers is cascading down the supply chains (Correll & Betts, 2022). The more complex and long supply chains are, the more likely the risk of having non-sustainable practices in the supply chain. Key conditions of the sustainability violations are limited monitoring of the SC and weak enforcement (Hofstetter & Grimm, 2019). SSCM practices are necessary to mitigate this risk.

There are two main **approaches to SSCM**: supplier assessment and supplier collaboration (Grimm et al., 2014), also known as supplier selection/screening and supplier development (Akhavan & Beckmann, 2017). Supplier assessment includes the evaluation of sustainability performance and compliance level. This assessment can be performed during the supplier selection process when the company chooses suppliers that are meeting their sustainability requirements or after signing a contract through regular supplier in-depth audits, supply chain mapping, and monitoring programs. Also, a company can rely on third-party assessments like certifications or sustainability ratings (ex. EcoVadis). Supplier collaboration aims at the improvement of suppliers' sustainability performance and relationships between buyer and supplier. This group of practices includes different supplier development programs (plans, trainings, and workshops that allow capacity building of suppliers, financial and expert support), corrective action plans, supplier's codes of conduct, etc. (Correll & Betts, 2022; Grimm et al., 2014). Grimm et al. (2014) also conclude that sub-suppliers' compliance with the focal company's sustainability standards depends on the level of the sustainability assessment and collaboration practices of the focal company towards its sub-suppliers (Grimm et al., 2016). Among key success factors for the implementation of SSCM practices are the trust and creation of mutual value instead of exercising power (Ebinger & Omondi, 2020).

SCV and SCT do not fall under the two approaches described above but rather represent the conditions that influence the chosen approach to SSCM, and SCV and SCT itself are SSCM practices. SCV is a precondition for both supplier assessment and collaboration strategies, and SCT, as a next step of SCV where SC information is communicated to the public, is both a result and a driver of effective supplier collaboration.

The figure below shows the rate of implementation of different SSCM practices. Among the most commonly used practices are suppliers' audits, supply chain mapping, and codes of conduct, which represent SCV practices, while SCT practices fall under information technologies implementation.

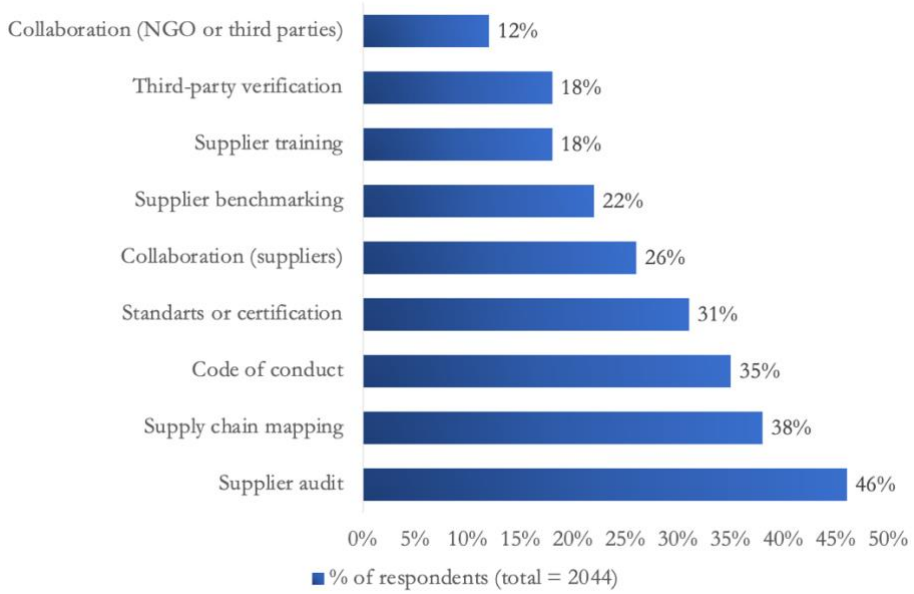

Figure 3-1. SSCM practices used by companies

Source: (Correll & Betts, 2022, p.12)

There are different ways to approach SSCM in multi-tier supply chains. Tachizawa and Wong define four types of governance mechanisms that a company can use to approach its sub-suppliers: *direct, indirect, work with third party*, and *don't bother* (described in more detail in the Theoretical framework section). Many factors influence the choice of governance mechanisms, including *power, stakeholder pressure, material criticality, industry, dependency, distance,* and *knowledge resources* (Gong et al., 2021; Tachizawa & Wong, 2014). In some cases, companies opt to combine *direct, indirect,* and *work with third party* approaches to achieve desired outcomes in the complex upstream segment of the supply chain (Gong et al., 2021). Mena et al. highlight that a "buyer who wants to influence key product characteristics needs to connect directly with its supplier's supplier who works with undifferentiated resources" (Mena et al., 2013).

Additionally, sustainability risk management is an essential part of SSCM. According to Choi, a supply chain risk is a negative event that can occur in the supply chain and "hinder the focal company's ability to meet its customers' demands" (Choi & Krause, 2006, p.645). Sustainability risks can be described as "environmental, social or governance events that, if it occurs, could cause an actual or a potential material negative impact" on the company's performance (EU Regulation 2019/2088, 2019) Supply chain complexity leads to the high level of freedom among actors and high probability of risk occurrence in SC (Choi & Krause, 2006).

Barriers and challenges can be internal (focal company's motivation and resources) or external (suppliers' resources and capabilities, motivation to cooperate with the focal company). One of the internal barriers for SSCM is the lack of a business case for implementing SSCM practices and the results can occur far in the future and there is lack of commonly accepted metrics to evaluate benefits from these activities. Ernst&Young study showed that one-third of the interviewed companies do not see a business case for supply chain sustainability, and half do not have metrics to evaluate return on investments in SSCM (Ernst & Young, 2022).

Supply chain complexity and a big number of actors in it cause high costs and resource intensity of SSCM practices like suppliers' audits and supplier development programs. In many cases, the company has to choose a small group of high-risk or large/significant suppliers to implement SSCM practices only among this target group. Lack of trust between supply chain actors, cultural and language differences, and geographical distance can lead to even higher costs of SSCM practices (Grimm et al., 2014). In many cases, lack of visibility beyond the first tier of suppliers makes the implementation of SSCM challenging (Ernst & Young, 2022). According to Grimm, "lacking information and transparency about supply chain partners, their processes or policies are major barriers for identifying and assessing sustainability risks in supply chains" (Grimm et al., 2014, p.162). Another problem is the lack of power of the focal company in the relationships with some suppliers that have strategic importance for focal companies (if there are no alternatives to the supplier on the market or transaction costs of changing suppliers are too high) (Grimm et al., 2014). Among external barriers is the complexity of the sustainability data collection process. It may take one year or more for suppliers to establish a system for data collection if it has not existed before (CDP, 2021). If a supplier represents a small or medium-sized enterprise, it may have limited resources and capabilities to comply with focal companies' requirements (Grimm et al., 2014).

Transition to sustainability in supply chains will involve new organizational, transaction, and cooperation costs. These costs are mostly carried by suppliers along the value chain, but at the same time, the premium for the sustainable product goes to the downstream producers. This disproportion leads to the failures of sustainability programs in the supply chains. "If one actor captures a disproportionate amount of the value collectively created the cooperation among partners will be broken, and other chain members are likely to give up on the initiative or to engage in cheating, fraud or deception" (Acquier et al., 2017, p.145). A core challenge for focal companies is the involvement of sub-suppliers' SSCM practices. As companies do not have direct contractual relationships and thus control over sub-suppliers, focal companies have to approach sub-suppliers through direct suppliers becoming dependent on their willingness to promote SSCM practices further up the supply chain (Grimm et al., 2014, 2018). Other authors that take a more systemic perspective suggest, that transition to the more sustainable practices in the supply chains cannot be imposed from the top or controlled as supply chains are constantly changing and their environment is dynamic, and sustainable development is an organic process that emerges as a result of cooperation and adjustments (Touboulic et al., 2018). While most SSCM research is conducted from the perspective of the focal firm, a more systemic approach acknowledges that upstream companies play a substantial role and are often overlooked in current research.

3.2. Supply chain visibility

According to Schafer, "SCV refers to a state in which specific information about the supply chain is available" (Schäfer, 2022). SCV includes the company's activities to collect and use data on their suppliers and buyers in any tier of their supply chain to form a holistic perspective for internal purposes (Sodhi & Tang, 2019). Simply, this means that focal companies try to obtain information on all their sub-suppliers to improve their supply chain management practices.

Many companies state that SCV is their top priority, but progress towards this goal is limited: only some companies confirm that SCV is actually increasing (Ernst & Young, 2022). Some studies conclude that by increasing SCV company can get a price advantage, increase purchasing power and reduce supply chain risks, ensure compliance with regulations, and meet customer demand (Ernst & Young, 2022; Kalaiarasan et al., 2022)). SCV helps companies "avoid, mitigate, and respond to supply chain disruptions" (Sodhi & Tang, 2019). SCV can also bring the company economic benefits as with increased visibility company can make better operational decisions about supply chains (Sodhi & Tang, 2019). SCV allows companies to ensure

compliance with regulations connected with supply chains and ensure risk and disruption monitoring (MacCarthy et al., 2022).

There is limited information on **SCV approaches** in the academic literature, which has a more clear focus on exploring SCT. One of the main tools used to achieve SCV is supply chain mapping and audits that allows to collect data from suppliers on their sub-suppliers sourcing the materials used in products (Correll & Betts, 2022; Fraser et al., 2020). Some digital platforms and services allow end-to-end SCV, for example, Sourcemap, Resilinc, and RiskMethods (MacCarthy et al., 2022). Supply chain mapping is a process of creating a schematic representation of a supply chain simplified model with both visualization and information about key features. Some studies define necessary conditions for SCV, including acceptance of information sharing in culture, collaboration between actors in SC based on mutual trust and creation of benefits for all parties, availability of technological infrastructure in different levels of SC (Kalaiarasan et al., 2022).

Hofstetter & Grimm highlight the following **barriers to SCV** implementation: "companies struggle with uncovering the identity of sub-suppliers in their supply chains" and "with every tier level upstream in the supply chain, focal companies' access to information becomes harder" (Hofstetter & Grimm, 2019, p.531). A big number of suppliers, their geographical spread, low willingness to share information among sub-suppliers, and low quality of information are the main barriers to SCV (Sodhi & Tang, 2019). The complexity of supply chains also leads to the high investments necessary to achieve SCV (Kalaiarasan et al., 2022).

Strategies to achieve SCV like SC mapping and audits take a long time and show some gaps due to the SC's high volatility. Audits can show sub-suppliers that have been already removed from the supply chain and not show the most recent suppliers. Risk-management systems based on audits rely on a static picture of the supply chain map, while it is constantly changing. Long-term recurrent audit programs can help in better monitoring changes over time and digital technologies for SCT can provide real-time information on the dynamic supply chains (Fraser et al., 2020). Other barriers to SCV include poor quality of information, and lack of knowledge, skills, and resources to ensure SCV, especially in low-tiers of supply chains consisting of a big number of small companies. (Kalaiarasan et al., 2022).

3.3. Supply chain transparency

Montecchi et al. provide the definition for SCT based on Bai and Sarkis paper: "Supply chain transparency is the practice of disclosing detailed and accurate information about operations and products, such as their origin and sourcing, manufacturing processes, costs, and logistics' (Bai & Sarkis, 2020; Montecchi et al., 2021). Information can be disclosed between actors within and outside the supply chain, for example, regulatory disclosure or disclosure to the public (Schäfer, 2022). Some studies suggest that SCT has three dimensions: range of transparency (e.g. operations scope, sustainability indicators), product transparency (e.g. material origin, chain of custody), participant transparency (e.g. participant operations and information) (Bai & Sarkis, 2020).

The important driver for the SCT is external pressure from the company's stakeholders on the collection and sharing of information on the sustainability of the supply chains (Schäfer, 2022). With the development of technologies stakeholders get more and more access to different information about the company's supply chains: a great amount of open data and new approaches to process big data allows NGOs and other stakeholders to conduct evidence-based reports on violations. This lead to stronger pressure on companies to justify their sustainability claims by being transparent about their supply chains (Montecchi et al., 2021). The 2011 report of the Institute of Public and Environmental (IPE) Affairs "The other side of Apple" is an

example of negative publicity on violations in the supply chain of Apple has led to the company started to publish a list of top suppliers and Supplier sustainability progress report (Sodhi & Tang, 2019). The trend to disclose names of top suppliers can be seen in other industries as well, for example among apparel companies like H&M (H&M Group, n.d.) and food like Nestle (Nestlé Global, n.d.).

SCT can create strategic benefits for the company, as it allows to "reduce search costs, aid the evaluation of authenticity claims, and highlight investments in corporate responsibility" (Montecchi et al., 2021, p.2). Also, it creates a signal to the investors, customers, and other stakeholders that the company is outright about its sustainability practices and aims to create trusting relationships (Montecchi et al., 2021; Sodhi & Tang, 2019). Among other benefits of SCT are reduced operational risks, more control of supply chain operations, reduced uncertainty, increased collaboration, openness, and resilience of SC (Montecchi et al., 2021). SCT can provide customers with confidence in the product's quality, safety, and ethical production, which will positively influence their willingness to buy the product (Bai & Sarkis, 2020). Also, it can "motivate green consumption by providing consumers with a better understanding of the product life cycle and product and process sustainability implications" (Bai & Sarkis, 2020).

SCV is considered to be a first step to **approach SCT**. When SC is mapped, and audits and supplier interviews are conducted, the company can decide where in supply chain disclosure is necessary. Some companies choose to disclose information about their top first-tier supplier, including name and location (ex.Apple, Nike, Marks, and Spencer) (Sodhi & Tang, 2019). If a company wants to go further up the supply chain in SCT, it can use digital technologies to enable SCT. IoT and sensors, blockchain, artificial intelligence, and big data analytics, cloud computing platforms are technologies that play a main role in the development of SCT in complex supply chains (Ebinger & Omondi, 2020; Montecchi et al., 2021). With a growing volume of open information available through the internet, it becomes harder to protect information about supply chains, thus it may be more efficient to disclose information voluntarily and approach the negative cases in SC proactively and build public trust or use it as a competitive advantage. Also, a company can reduce the costs of supplier monitoring by increasing SCT and allowing the public and NGOs to search and report on concerns and violations (Sodhi & Tang, 2019).

Traceability is the commonly mentioned tool for ensuring supply chain transparency. It describes the company's capability to collect, monitor and verify information about the product's materials origin and chain of custody (Ebinger & Omondi, 2020; Montecchi et al., 2021). If SCV describes the capability to acquire information about actors in all tiers of SC, traceability is related to the specific capability to track the material flow of each unit of product from the raw material origin to the end product or even beyond that, allowing to trace materials in the end-of-life phase as well. Traceability can be set in both ways from upstream suppliers to the focal company and from the focal company to downstream buyers (Ebinger & Omondi, 2020). Blockchain technology is viewed as one of the main solutions to enable the traceability of products (Gligor et al., 2022). Blockchain allows to store data about the origin and every transaction with the raw material across the supply chain. Using blockchain for SCT "offers more opportunities for disclosure, and it also allows companies to better detect poor practices in the supply chain" (Gligor et al., 2022, p.154). SCT requires new capabilities and solutions. It is still a young field with many projects of digital technologies applications for SCT transparency being in the pilot stages and mostly driven by private initiatives (Ebinger & Omondi, 2020; Gligor et al., 2022).

There are several **barriers in SCT** implementation process. Before disclosing information it should be collected from a big number of actors in SC, which requires time and money, especially if the SCV is not yet achieved (Sodhi & Tang, 2019). Also, it is challenging to gain visibility beyond the first tier of suppliers due to the supply chain's complexity which makes SCT "difficult, costly, and time-consuming" (Schäfer, 2022). Integration of new technologies in established supply chain management processes is one of the biggest challenges (Bai & Sarkis, 2020). A lack of technological capabilities and technological infrastructure among some actors in SC can create barriers to SCT implementation (Kalaiarasan et al., 2022). Moreover, a big volume of collected information on SC actors, materials, and products should be stored, protected, processed, and utilized in an efficient way (Ebinger & Omondi, 2020; Montecchi et al., 2021). Another identified challenge is the fact that "data and information transparency always carry the risk of disclosing business secrets, copyright issues, or confidentiality issues" (Ebinger & Omondi, 2020, p.6), thus there is a resistance towards transparency among the different supply chain actors. Some companies in the supply chain can perceive information about their suppliers as a competitive advantage, and thus refuse to share it with anyone (Ebinger & Omondi, 2020).

For the focal company, SCT can lead not only to benefits but also make a company an object for "name and shame campaigns" and reputational risks (Garcia-Torres et al., 2022). If the disclosure of the information is not full, a company can be accused of hiding the information. If some negative cases will happen with a supplier in a disclosed SC, the company will not be able to claim that it did not have enough information about the supplier's practices. Also, disclosing some information can cause a negative reaction from customers, or in other cases meet their neutral reaction without a willingness to pay price premiums for transparency (Sodhi & Tang, 2019). In many cases, the value of SCT can be unclear to the companies due to the lack of metrics to measure the impact and existing business cases (Ernst & Young, 2022; Sodhi & Tang, 2019). Some authors suggest that the negative effects of the disclosures (in the form of compliance costs like regular audits, reporting, etc.) outweigh any positive effects (for example, the increased value of a company or its products) (Griffin et al., 2014).

3.4. Digital technologies for supply chain management

As a response to growing pressure from stakeholders and legislation, many companies started to develop and implement digital technologies for supply chain management. The high complexity of supply chains and a big number of actors in them determine the great amount of data that needs to be collected, analyzed, and utilized in the decision-making process. High dynamics of supply chains demand that data should be processed near real-time so the focal company can make timely decisions on the identified risks (Ebinger & Omondi, 2020). Digitalization of supply chains means the application of technologies like blockchain, the internet of things (IoT), big data analytics, and others that allow to connect physical and digital objects for more efficient supply chain management. Main benefits of digitalization are "increased availability of information, optimization of logistics practices, real-time data collection, more efficient inventory management, and increased transparency" (Bigliardi et al., 2022, p.1806-1807).

Ebinger&Omondi define four groups of digital technologies most mentioned in the context of sustainable supply chain management: blockchain, artificial intelligence and big data analytics, cloud computing platforms, and IoT-sensors-driven application (Ebinger & Omondi, 2020). *Blockchain* is a shared digital transaction ledger consisting of cryptographically secured time-stamped records that every user can inspect but is still secure since no single user can control or tamper with the data stored in the blockchain" (Malik et al., 2021). *Blockchain technologies* enable the tracing and tracking of products from upstream to downstream users and storing information about the origin, chain of custody, sustainability certificates, and other data in a

secure way (Ebinger & Omondi, 2020). *Artificial intelligence (AI) and big data analytics* is a set of technologies that allows the collection and processing of a big amount of data allowing close to real-time access to these data. Predictable analytics allows better risk identification and management. AI can identify patterns in data that can be used for the decision-making process (Ebinger & Omondi, 2020). *Cloud computing platforms* represent "multi-agent systems operations tools used for SC mapping and information sharing" (Ebinger & Omondi, 2020). Using these platforms focal companies can collect in a unified and efficient way sustainability data from a big number of suppliers and sub-suppliers and increase the supply chain visibility. It also allows information sharing and disclosure and stimulates industry collaboration (Ebinger & Omondi, 2020). *IoT-sensors-driven application* represents "connected ecosystems of sensors that facilitate massive collection and processing sustainability-related information". IoT sensors ensure real-time data collection on production, logistics, environmental conditions, etc., and its delivery to the end user. This allows companies to improve supply chain visibility, and monitor and forecast risks. IoT sensors help to collect data that can then be transmitted along the value chain using blockchain technologies, be processed by AI and big data analytics solutions, stored and accessed by the end user through a cloud computing platform (Ebinger & Omondi, 2020; Malik et al., 2021). Ernst&Young's 2022 survey among 525 large corporations showed that digital technologies have been actively implemented in sustainable supply chain management (Ernst & Young, 2022).

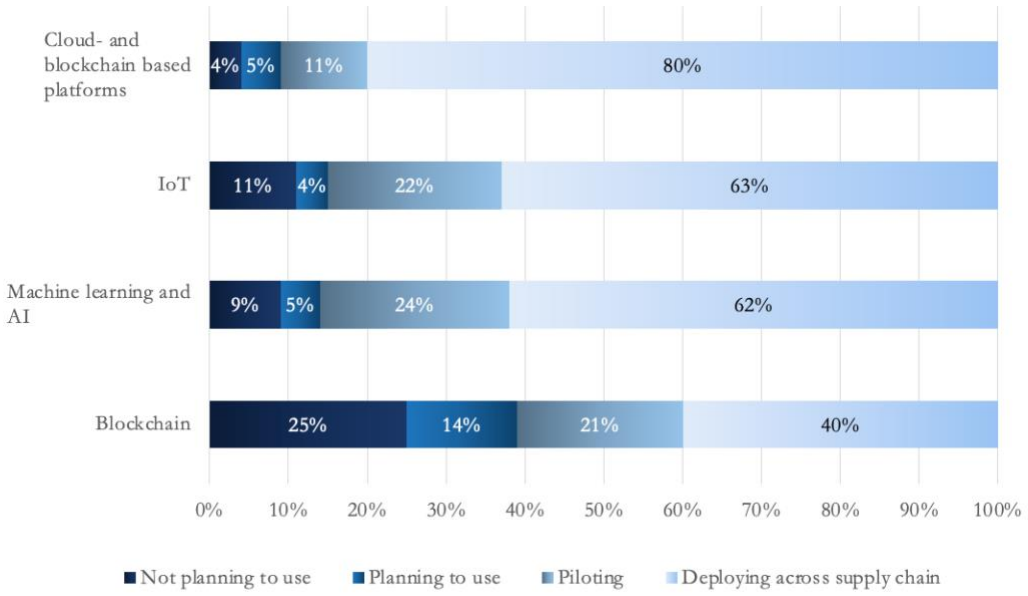

Figure 3-2. Implementation of digital technologies in SSCM practices

Sources: own illustration based on Ernst & Young, 2022

3.5. Discussion

There is no consensus on the definitions and relationships between SCT, SCV, and traceability. Schafer discusses that in different these concepts are equated, or viewed as independent concepts, necessary conditions, or parts of each other (Schäfer, 2022). Some studies highlight that SCT is a key requirement for successful SSCM (Ebinger & Omondi, 2020; Fraser et al., 2020; Montecchi et al., 2021). and that SCT leads to better supply chain governance and enhances the accountability of supply chain actors (Ebinger & Omondi, 2020). SCT "forms a deliberate strategy to integrate and extend supply chain visibility beyond the boundaries of the organization and its suppliers by allowing external stakeholders (e.g., customers, investors)

access to detailed supply chain information" (Montecchi et al., 2021). Based on the literature review, a preliminary scheme of interrelationships between concepts was developed.

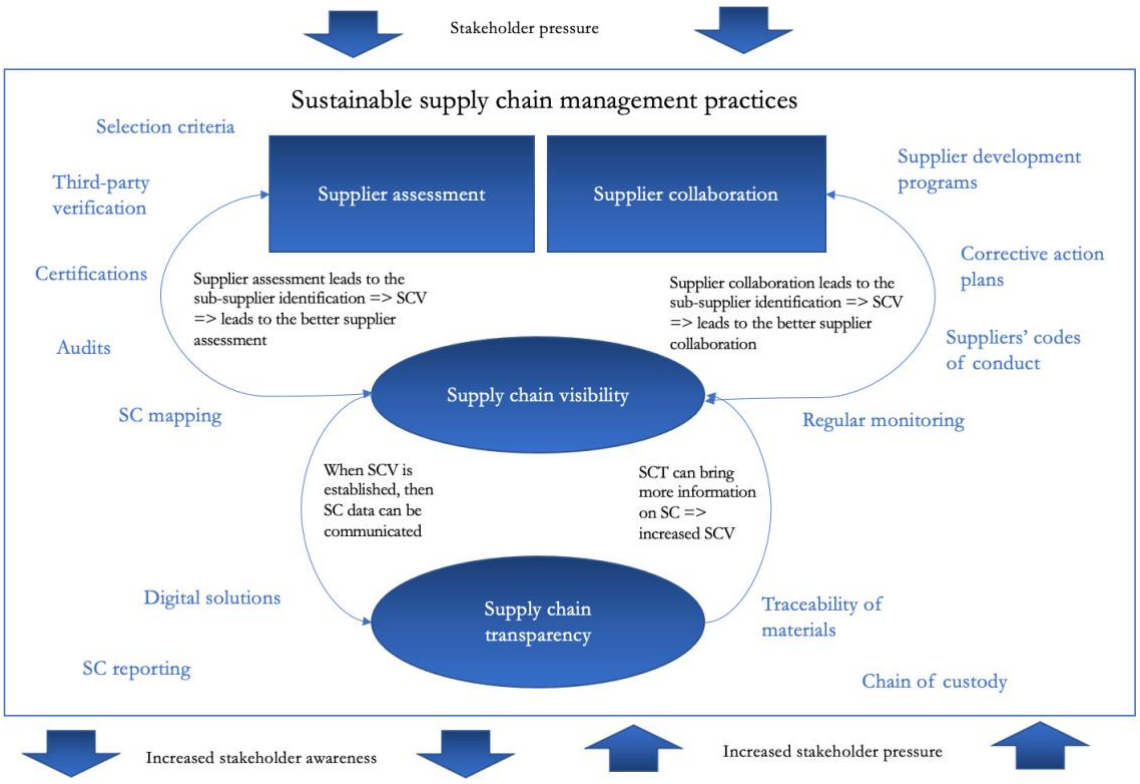

Figure 3-3. Preliminary scheme of interrelationships between SCV, SCT, SSCM

Source: own illustration based on literature review

SCV can be defined as "a preliminary stage in sharing information". But at the same time to achieve visibility information should be disclosed first among the supply chain actors (Sodhi & Tang, 2019). This leads to the assumption, that information disclosure as a result of SCT implementation will result in increased SCV, and the two concepts are mutually dependent. Visibility and transparency are essential steps in the SSCM in complex, geographically spread multi-tier supply chains. But after this step, companies need to enforce changes in suppliers' behaviors through other SSCM practices to ensure the achievement of sustainability goals and respond to stakeholders' pressure (Hartmann & Moeller, 2014; Montecchi et al., 2021). SCT helps "to monitor and communicate how organizations meet social and environmental sustainability targets" (Montecchi et al., 2021). There is still a debate over the positive and negative benefits that SCV/SCT can bring to the company (Montecchi et al., 2021), thus more research is needed on the motivations and barriers for their implementation. Current research also focuses mostly on focal companies and lacks information on upstream companies, while their participation can be crucial for the success of SCT practices.

For the further development and implementation of SCV/SCT key success factors should be explored, including engagement strategies with stakeholders, knowledge transfer and supply chain actors' capabilities, etc. Also, external drivers, perceived benefits, and drawbacks can differ between companies of different industries, different sizes, geographic locations, and different customer segments. Thus, further research can explore how different external and internal factors influence companies' position towards implementing SCV/SCT and how it influences their SSCM strategy.

4. Research Design & Methods

In this chapter research design and methods for data collection and analysis are described and justified with a discussion of possible limitations and measures to mitigate them.

4.1. Research design

The main aim of the research is to explore the process of achieving sustainability goals in large multinational companies with complex multi-tier supply chains through increasing visibility and transparency of supply chains. Despite growing attention to the visibility and transparency in the supply chain management literature, many knowledge gaps exist on how companies choose approaches to SCV/SCT, how they perceive benefits from these activities, and how they influence overall sustainability strategy and performance indicators. According to Creswell&Creswell, "if a concept or phenomenon needs to be explored and understood because little research has been done on it or because it involves an understudied sample, then it merits a qualitative approach" (Creswell & Creswell, 2018, p.57). The dominant researcher's worldview is pragmatic, as it supposes "to look to the what and how to research based on the intended consequences" and expected outcomes and recognize the significance of context (Creswell & Creswell, 2018). Qualitative research design allows a better understanding of SCV and SCT as concepts, their drivers, barriers, necessary conditions, available technologies, benefits, and shortcomings. The study evaluates the problem and to what extent existing solutions are helping to solve the problem. This will allow to provide necessary knowledge for wider implementation of SCT practices as a part of SSCM in large multinational companies with complex multi-tier supply chains. Moreover, this qualitative study can provide the foundation for further quantitative studies that test the relations and mechanisms that are identified in this work.

Qualitative design is often characterized as emergent, where the initial research plan can be changed in the process of data collection and analysis, as well as research questions can be refined. Qualitative research aims to provide a holistic perspective on the phenomenon under study, including "reporting multiple perspectives, identifying the many factors involved in a situation, and generally sketching the larger picture that emerges" (Creswell & Creswell, 2018, p.258). While quantitative research is still the dominant research method in the field of business, qualitative methods are often seen as less rigorous or less credible than quantitative methods (Bansal et al., 2018). At the same time, qualitative methods offer unique strengths and advantages that cannot be achieved through quantitative methods alone, like gaining a deeper understanding of complex social phenomena and providing rich and detailed descriptions of organizational processes and behaviors. Qualitative methods also allow for greater flexibility in research design and can be particularly useful for exploring new and emerging phenomena like SCV and SCT in minerals supply chains (Bansal et al., 2018).

This study concludes a two-year master's program, an essential part of which was an internship conducted in the field of this research. This allowed the researcher to be embedded in the study setting and to get first-hand experience in the studied area, and participant observation was used as an additional tool in this research. Participant observation is a specific technique that involves immersing oneself in the social setting being studied and actively participating in the daily activities and interactions of the people being studied. The researcher observes and records what happens, takes notes, and engages in conversations with the participants to gain a deep understanding of their perspectives, experiences, and behaviors (Watson, 2011). Reflections, analytical and observational notes created during the internship became a base for this study and allowed to create a study design with a focus on practitioners' needs. At the same time, interviews, reports, webinars, and other materials collected through this study allowed to triangulate and cross-check the conclusions. Despite its potential to provide valuable insights into organizational phenomena, participant observation is underused in business research. One

reason for this is that they are often perceived as being too time-consuming, resource-intensive, and subjective. However, participant observation is crucial for gaining a deep and nuanced understanding of organizational phenomena, particularly those that are complex, messy, and difficult to capture through other methods. It allows researchers to uncover the underlying processes, power dynamics, and social interactions that shape organizational life, and to generate new and unexpected insights (Watson, 2011).

The main focus of the study is minerals supply chains, as they can be characterized as essential raw materials for many consumer and industrial projects, they are a bottleneck in the green energy transition, minerals supply chains are extremely complicated and consist of many tiers of suppliers located all around the world (more information on the structure and challenges of minerals' supply chains are provided in section 5.1). This makes SSCM for minerals challenging, and based on the literature review, it remains insufficiently studied. The main approach to the data collection and analysis is multi-perspective, and research includes perspectives of different actors of supply chains (downstream, midstream, upstream), third parties (industry associations, technology providers), and different industries (automotive, consumer electronics, industrial solutions). In this research, information is collected using multiple sources of data, including 47 published documents from 16 companies operating in the automotive, electronics, consumer goods, and industrial goods industries, including corporate websites, sustainability reports, and press releases. Additionally, 5 webinars and 10 reports from industry associations and consultancies were utilized. 7 interviews with practitioners are conducted to fill the gaps from the desktop research and enrich it with insights. Having multiple sources of data allows data comparison or triangulation, which helps to increase the research validity by minimizing the influence of the researcher's bias.

4.2. Data collection methods

In a qualitative study design participants are purposefully selected to allow the researcher to get the best understanding of the problem. Following a multi-perspective approach, the following industries and companies are chosen for desktop data collection based on the presence of critical minerals in their supply chains, and the multi-tier character of their supply chains: automotive (Tesla, Volkswagen, Audi, Stellantis, Volvo Group, Toyota, BMW), consumer electronics and other goods (Apple, Samsung, Phillips, Sony, IKEA), industrial manufacturing (Siemens, ABB, Atlas Copco, Caterpillar), referred as "studied companies" in this document. Downstream companies' practices are the main focus of this study as they are the main influencers in the supply chains, cascading their requirements along the supply chain and establishing SCV/SCT practices as a response to the stakeholders' pressure. In addition, where possible perspectives from relevant midstream (e.g. Umicore) and upstream (e.g. Glencore, ERG) companies, technology providers, and industry associations were added. Adding upstream and midstream companies' perspectives allow to explore the complexity of SSCM and the challenges associated with these tiers of supply chains. Technology providers and industry associations as well provide their vision of the challenges and possible solutions to them that can enhance the study and make it holistic. The collection of multiple perspectives also aligns with the application of CAS theory which explores systems with multiple actors and connections between them. Chosen companies are located in different geographies, have different levels of importance of critical minerals for their businesses, and have different levels of SSCM practices maturity. Having diverse companies in scope allows to extract different practices ranging from basic to advanced.

In this study, data on SSCM was primarily gathered from company websites and sustainability reports. If separate reports on critical/conflict minerals supply chains were available, they were also collected and analyzed. This method of data collection allowed for an in-depth examination of research questions during the interview process, as all publicly available information was gathered beforehand. After that, people from different industries and roles in the value chains

were interviewed for the data collection, including downstream / midstream / upstream producers, technology providers, and industry associations. This allows to provide different perspectives on the topic. All prospective participants are found and contacted using professional social network platforms (e.g.LinkedIn) and the researcher's own network. Several criteria determined the choice of participants: (1) expertise and position; (2) experience in the identified industries; (3) experience in responsible sourcing / SSCM; (4) availability for the interview. The participants were also selected to cover different perspectives on the study area: downstream companies with different levels of importance of critical minerals for their business; midstream companies; upstream companies; industry associations; technology providers. Access to study results is offered to the participants as an incentive.

Chosen methods for the data collection are provided below.

Table 4-1. Data collection methods

Research question	Data collected	Data collection methods
RQ1: what role do SC visibility and transparency play in the SSCM process	Researchers' and stakeholders' positions on SSCM/SCT/SCV	• Literature review • Semi-structured interviews with sustainability managers involved in SSCM
RQ2: what approaches do large multi-national companies implement to achieve SC visibility and SC transparency and what different factors influence a company's choice of approaches to SCV and SCT	• Current documented or observed SCT/SCV practices in focus industries • List of factors that determine the choice of approaches to SSCM and SCV/SCT to achieve the company's sustainability goals • Main types of solutions for SCT existing on the market	• Desktop research on solutions for SCT/SCV and business strategies • Semi-structured interviews with sustainability managers involved in SSCM • Semi-structured interviews with SCT technologies providers
RQ3: what are key challenges and success factors in the process of establishing SCV and SCT	• Current hotspots and challenges in SCV/SCT for sustainability managers of big multinational companies • Success factors and necessary conditions for the implementation of new technologies for SCT/SCV	• Literature review • Semi-structured interviews with sustainability managers involved in SSCM • Semi-structured interviews with SCT technologies providers

Source: own research

The data collection process is conducted in several steps. First, sustainability reports and websites of the companies listed above are investigated. Usually, they have special sections on the sustainability of supply chains and responsible minerals programs. Second, relevant published interviews, journal articles, webinars, and industry reports are examined to gather more detailed information and different perspectives. Third, semi-structured interviews are conducted after the primary desktop research to get deeper insights on the findings. Interviews are held online using videoconference tools (e.g. Zoom, Google Meets, Teams). Interview guides are developed for each participant group (focal companies, raw material producers, technology providers, etc.), and each interview is recorded, transcribed, and coded.

Interviews were conducted using a semi-structured questionnaire that allows to tailor questions to the highly diverse participants, but at the same time to collect comparable data. All questions were open-ended. Interview guides were further adjusted based on the insights gained in prior interviews. Additional questions were asked where they were relevant to the participant's experience. The interview duration was 30-60 minutes, depending mostly on the interviewee's

knowledge of the subject and experience. Interviews were recorded, where participants provided consent for that, and transcribed using the software. Interviews allowed to collect a sufficient set of information for further evaluation.

4.3. Data analysis methods

All collected data from multiple sources is organized using a coding system developed based on the literature review and theoretical framework, representing a deductive approach. Then after data is collected, codes are revised during the coding process based on the new information, representing an inductive approach.

All data is analyzed using NVivo software that allows to code collected data and then synthesize information collected under each code. For the data analysis, the primary list of codes was developed based on knowledge gathered from the literature review. During data analysis codes are revised: some code categories are unified, subdivided into more specific codes, or complemented with new codes. All relevant data from desktop research is collected, coded, and stored in NVivo based on code structure. Information is analyzed under each code and then key themes were synthesized to provide answers to the research questions. Interpretation of the results is conducted by summarizing findings by themes, and their comparison to the propositions formulated as the result of the literature review.

4.4. Limitations

The major limitation of this study is the time constraints. In the given timeframe it was possible to analyze data from a limited set of companies, and the final results highly depend on the companies' selection. In this study strategic sampling was used: companies' diversity was prioritized to collect the most popular SSCM practices and identify the different levels of development of their approach, allowing to extract the important insights in the given time constraints (Patton, 1990). This does not allow to compare industries or companies within industries, and the results of the study can only be used to illustrate the different approaches and tools that companies use in SSCM of critical minerals.

Most of the data was collected during February 2023, when most of the companies had not published their 2022 reports, and therefore 2021 sustainability reports were used for the study. This may not represent the actual picture, as new projects and technologies develop at a high pace. To minimize this limitation, actual information from corporate websites was used where possible. As only big multi-national companies with a significant share of minerals in their supplies have special programs for responsible minerals sourcing, the choice of prospective interview participants was limited, and in the given timeframe it was difficult to find more relevant participants for the interviews.

In general, the choice of qualitative study design can raise concerns about the generalization, reliability, and validity of data. Qualitative research methods are not designed for statistical generalization, they offer valuable insights into the specific context under scrutiny. This in-depth understanding can be instrumental in formulating hypotheses and theories, which can subsequently be tested using quantitative methods. As such, qualitative research can complement quantitative research and provide a foundation for further empirical investigation. Although data was triangulated where possible, it is still important to point out that the study is based on a limited sample of companies and interviews, and some of the formulated conclusions may not be relevant for all companies in the critical minerals industry due to the high number of diverse actors.

5. Findings

In this section, an overview of critical minerals supply chains is provided using MTSC and CAS frameworks. In section 5.1 key factors that influence a company's approach to SSCM are analyzed using the list of factors from MTSC theory. In section 5.2 data on approaches to SSCM, SCV, and SCT is presented based on governance mechanisms described in MTSC theory. Finally, in section 5.3. the data is analyzed from a CAS perspective that allows to include supply chain complexity factors and dynamics in the conclusions. The logic concept of the Findings section is presented below (Figure *5-1*).

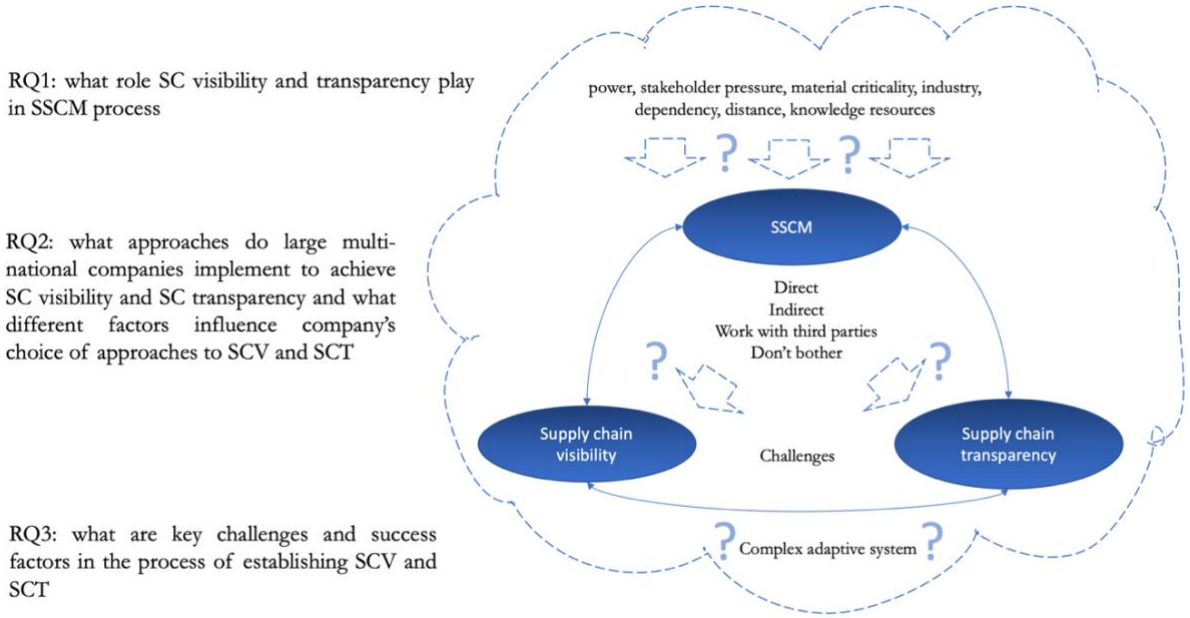

Figure 5-1. Research questions

Source: own illustration

5.1. Factors influencing the choice of approaches to SSCM

Minerals supply chains are characterized by long distances and high complexity. Focal companies supply their products from a big number of suppliers: it can be 10.000-60.000 suppliers from 50-100 countries just at the tier-1 level (Audi, 2023; Toyota, 2021a; Volkswagen Group, 2021b). The number of indirect suppliers is even bigger, for example, Siemens reports that they have "65,000 suppliers in about 145 countries", which makes it impossible to "oversight for every supplier" (Siemens, 2023). Mining sites are spread all around the world and are often located in regions with weak legislation, severe human rights violations like forced and child labor, and ongoing armed conflicts (more in 0, subsection Material Criticality). For example, artisanal and small-scale mining (ASM) of cobalt "accounts for about 30 percent of production in the Congo, miners dig deep tunnels with their hands or very simple tools to get to the cobalt – and these tunnels often collapse. In some areas, children also help with the mining" (Audi, 2021a). Cobalt, lithium, nickel, and other minerals "are essential to build the electrified future required to avoid the worst consequences of climate change. Yet, each of these supply chains has an environmental and social footprint that goes unmeasured and often undetected" (Barbosa et al., 2022).

Minerals supply chains are extremely complex, as there are many third parties involved (e.g. traders) and minerals are processed multiple times (Figure *5-2*). Most of the midstream

companies (refiners, smelters) are located in China, and downstream companies are concentrated in the EU and USA. This characteristic of minerals supply chains creates many opportunities to mix materials from different sources along the supply chain and makes the assessment and verification of material origin challenging. «Determining the mine of origin for these minerals requires the cooperation of many levels of suppliers and intermediaries in the supply chain» (Sony, 2022) High dynamics, a big number of actors in supply chains and different power dynamics create even more complicated system.

Figure 5-2. Simplified map of battery minerals supply chains

Source: own illustration

For the analysis of factors influencing the company's choice of approaches to SSCM, the list of factors from the multi-tier supply chain theory was used. Factors include power, stakeholder pressure, material criticality, industry, dependency, distance, and knowledge resources (Gong et al., 2021; Tachizawa & Wong, 2014).

Stakeholder pressure and Industry

Stakeholder pressure can influence the company's behavior in several ways. Big well-known companies and brands are usually an easy target for stakeholders that want to attract attention to the specific issue [B]. Such companies can regularly become a target of negative media campaigns that damage their reputation. For example, Apple and Tesla are accused of the violation of human rights in the DRC's cobalt mines, even though there is no evidence provided on their sourcing from the specific mines with violations. The high complexity of the supply chains and low knowledge of the general public on the supply chain structure makes it difficult for companies to protect their reputation (Smith, 2023). This stimulates companies "to adopt a more proactive approach and establish direct links with any agent that can contribute to the sustainability of the supply chain" (Tachizawa & Wong, 2014). This is confirmed by the practitioners: "We all know that there are negative social and environmental impacts connected with critical minerals. If we want to follow our sustainability strategy and keep our promises to the consumers, then we can't say we don't do anything in critical minerals supply chains" [B].

Stakeholder pressure is growing in all markets and segments [A, B, C, D]. On one hand, the pressure is coming from customers as more information on human rights violations and environmental issues becomes available and becomes a more widely discussed topic in media. At another hand, there is growing pressure from the legislation, especially in the EU and USA (see section 2.2). Siemens state in their report on the supply chains: "Within the recent years numerous pieces of legislation were published and require our absolute attention. Besides others, EU law on environmental protection and human rights came into effect as well as legislation in USA, UK, France, Denmark, Australia, and Germany" (Siemens, 2023). This is also confirmed by practitioners: "before, the reporting standards like GRI, SASB and others didn't have such strict supply chain requirements, they were asking more about the company itself, about disclosure. Now it's moving towards CSRD, and CSRD along with IFRS say it's important to go and disclose along the supply chain, look at who your suppliers are, and see what their footprint is, and other indicators, keep track of them all. And now in all the standards and ratings, customer questionnaires, everywhere, are questions: do you audit your suppliers,

how do you work with your suppliers, and how do you ensure that they're compliant? That's the way it goes, and this trend will continue" [A], "Presently, the main pressure comes from the European Union and the coming legislation, the CSRD. We have been collecting and measuring our impact from the operations for many years and reporting on that impact, but we will need to look into more details on the supply chain level, fulfilling the sustainability due diligence principle and the value chain approach in order to perform a proper double materiality analysis. We also get lots of customers' requests that initially were focused primarily on our scope one and two, but we know that scope three will be increasingly in focus of these requests as well. So, we will need data from our supply chain in order to be able to satisfy the customer requests and to be able to drive our sales forward" [C].

Another driver of growing stakeholders' pressure is decarbonization goals. As many companies start to calculate their GHG emissions and start to set reduction targets, they have to deal with supply chain emissions (scope 3) as it is a major source of emissions (CDP, 2019; Deloitte, n.d.). "Scope three emissions, predominantly purchased goods and services, stand for 80% of our entire carbon footprint, which is why supply chain sustainability will be more and more interesting and relevant, both in terms of the procurement practices, but also in terms of our sustainability footprint" [C].

This pressure is felt the most in the automotive sector, which expects the new EU Battery regulation to come into force in 2023 with the requirements on supply chain due diligence. This is also confirmed by the midstream and upstream producers in the automotive supply chain, as they state that the most pressure for sustainability compliance come from the automotive clients [A, C]. Such pressure on the automotive sector can be explained by the growing electrical vehicle (EV) market and its dependency on EV batteries, and "batteries touch the most critical points" (RCS Global Group, 2022). "The pressure is the strongest on companies working directly towards consumers, B2C: automotive, fashion, food industries and all other industries. In our case, Automotive is definitely one of the strongest drivers of visibility. They have been probably the most active stakeholder driving the sustainability agenda forward, sending requests, collecting our data in order probably to be able to calculate their scope three and to fulfill their customer pressure" [C]. Even if the producer is not in the scope of regulation, stakeholder demand can be high enough for the companies to change their practices. For example, "Atlas Copco is not in the scope of Dodd-Frank Act or the EU regulation 2017/821, but based on concerns of violations of human rights including forced labor, human trafficking, and child labor, and to support our customers' obligation to these Acts, the Group has measures to detect and prevent the use of conflict minerals in its supply chain" (Atlas Copco, 2021).

Material criticality

The more critical materials are, the more focal companies are motivated to have direct connections with lower-tier suppliers (Tachizawa & Wong, 2014). All materials differ by their level of criticality for the specific industry. There are more than 50 raw materials used in the production of modern cars and electronic devices, with different levels of criticality and sustainability challenges (Drive Sustainability et al., 2018). Among analyzed companies, three levels of approach to the critical minerals' identification can be found based on the studied companies' report (Table 2-1):

- Compliance, meaning that companies aim to follow the regulatory requirements that are now most developed for the conflict minerals (3TG: tin, tantalum, tungsten, gold)
- Beyond compliance, meaning that beyond required compliance on 3TG, companies establish SSCM practices for the 1-3 most critical minerals, in most cases cobalt, nickel, and lithium.

- Comprehensive, meaning that all critical materials are identified and evaluated and SSCM practices are established towards a wide range of critical materials.

Table 5-1. Critical or high-priority minerals for different producers in the scope of this study

	3TG	Cobalt	Nickel	Lithium	Other relevant
Automotive					
Tesla	+	+	+	+	mica
VW	+	+	+	+	+9 raw materials
Audi	+	+	+	+	+9 raw materials
Volvo Group	+	+			
Stellantis	+	+	+	+	Graphite, Mica
Toyota	+	+			
BMW	+	+	+	+	Mica, copper, other
Consumer goods including electronics					
Apple	+	+		+	
Samsung	+	+		+	Mica
IKEA					14 inorganic raw materials
Phillips	+	+			
Sony	+	+			
Industrial products					
ABB	+				
Siemens	+				
Atlas Copco	+	+			
Caterpillar	+				

Source: companies' sustainability reports

There are many criteria to evaluate the criticality of materials. In the Drive sustainability report there are 16 criteria identified in two groups "Importance to industry" and "Association with sustainability issues", representing direct and indirect business importance. Importance to industry "indicates the degree to which the automotive or electronics industry relies on a material to manufacture its products, the supply vulnerability of that material, and the potential influence of the industry sector on a material's supply chain by virtue of its proportional consumption of global production". Association with sustainability issues "indicate the extent to which production of a material is associated with adverse environmental, social or governance impacts that affect upstream communities and wider society and present a risk to corporate reputation" (Drive Sustainability et al., 2018, p. 24). Sustainability issues include among others: the presence of forced or child labor, % of minerals mined by artisanal and small-scale miners (ASM), high CO2 emissions, the potential for harm from hazardous materials and chemicals, etc. Several companies justify the prioritization of some critical minerals. For example, Tesla uses criteria "Commercial importance" and "Potential environmental and social impact and scrutiny": "Cobalt, lithium and nickel are the key raw materials used in cathode production, represent about a third of the total costs of a battery cell and play an essential function in improving vehicle range and safety performance. Cobalt, lithium and nickel are often concentrated in countries that face socio-economic and environmental challenges. As known global reserves are depleted, these minerals are becoming increasingly scarce" (Tesla, 2021).

Material criticality is a significant concern for companies across various industries, given the widespread use of critical minerals. However, the level of risk and stakeholder pressure varies for different minerals, leading to different approaches to SSCM. It is important to note that the criticality of these minerals is expected to increase in the future, and this trend is unlikely to change unless new, abundant sources of minerals are discovered.

Power and Dependency

Power dynamics play a crucial role in the implementation of sustainability standards in supply chains. The ability of a company to transmit its sustainability standards to its suppliers is heavily influenced by power imbalances within the supply chain: "Critical minerals are the one area where we are super small, we are not considered being the significant player by the suppliers and are limited in our influence" [B]. When a powerful member of the supply chain enforces sustainability standards, lower tiers are more likely to comply. The power dynamic between buyer and supplier can also depend on the volume of products being purchased. If the buyer is a major client by volume, the supplier will be more willing to collaborate and comply with sustainability standards [D].

Legal requirements can also influence power dynamics. When sustainability standards are legally binding, the focal company has more power to push these standards throughout the supply chain [D]. However, even if the requirements are not legally binding, there is still potential for focal companies to leverage their market power to push for better sustainability practices. In some cases, focal companies may use their purchasing power to incentivize suppliers to improve their sustainability practices. By doing so, they can help drive sustainability improvements throughout the supply chain.

Dependency is a major challenge for many companies, particularly those that rely heavily on specific minerals or materials in their products. For example, the production of batteries is highly dependent on specific formulas and minerals, such as lithium, cobalt, and nickel. These materials are crucial to the performance and safety of batteries, and there are often limited alternatives available. In addition, some minerals are closely linked to specific geographic locations, which can create significant risks for supply chain management. For example, more than half of the world's cobalt comes from the Democratic Republic of Congo, which has been associated with human rights abuses and environmental degradation. This dependency on a single country for such a critical mineral highlights the importance of effective SSCM to ensure responsible sourcing and minimize risks to the company and its stakeholders.

As demand for critical minerals continues to grow, the challenge of managing dependencies and ensuring responsible sourcing will only increase. Some companies work towards reducing supplier dependency, but it may not be a working strategy for all critical minerals.

The success of SSCM practices and the level of resources invested in such practices are influenced by power dynamics and dependency in the supply chain. These factors play a crucial role in determining the likelihood of effective implementation and the level of resources companies are willing to invest in their SSCM efforts.

Distance and Knowledge resources and other criteria

Many companies that were studied emphasize the extensive reach and dynamic nature of their supply chains. For instance, BMW (2023) characterizes its supply chains as far-reaching and constantly evolving. The complexity of implementing SSCM practices becomes evident when considering the multitude of suppliers involved, even within the first tier. This challenge arises due to both geographical and operational distances. Geographically, supply chains have become globalized, with specific facilities located in various parts of the world. In minerals supply chains, for example, mining processes are primarily concentrated in Africa and South America, while key processing facilities are situated in China for refining, smelting, and component production. Furthermore, final product assembly often occurs in Europe or China. Operationally, the high

number of tiers within the supply chain exacerbates the challenge, with minerals supply chains commonly consisting of 5-9 tiers or even more between the mining site and the end product.

Supply chain actors exhibit diverse knowledge resources, further complicating the implementation of SSCM practices. Different parts of the supply chain may have contrasting approaches and capabilities, necessitating adaptable practices to accommodate these variations. It is important to recognize that certain regions or entities may still rely on traditional methods such as Excel spreadsheets and on-site audits, which are likely to persist for an extended period. The introduction of new reporting requirements poses a considerable challenge for suppliers who have not previously encountered such inquiries from their customers. As a result, the reporting burden will increase significantly for all participants in the supply chain.

In conclusion, all seven factors identified in the MTSC theory are relevant for choosing a SSCM approach for the minerals supply chain. Although, it is clear that for some minerals and industries stakeholders' pressure is higher and some minerals have "higher criticality" compared to others. Distance and Knowledge resources are factors that seem to be relevant for most multi-tier supply chains and should be considered more as barriers than differentiation factors. In contrast, Power balance and Dependency seem to be unique for each company and are considered when choosing the SSCM approach.

5.2. SSCM approaches and best practices

In this section, first, general approaches to the SSCM are reviewed with a focus on minerals supply chains to understand the context of where SCV and SCT fit in SSCM. Second, practices to achieve SCV and SCT are described. Third, the challenges of achieving SCV and SCT are analyzed. Finally, the section concludes with a description of possible connections between the three concepts.

Strategies and approaches to SSCM of critical minerals supply chains differ among studied companies. There are examples of all four governance mechanisms identified by Tachizawa & Wong: *direct, indirect, work with third parties,* and *don't bother* (Tachizawa & Wong, 2014). At the same time, there is no clear borderline between some approaches, and there are no companies that use a single approach (Heldt & Beske-Janssen, 2023). One example, a company can have policies, codes of conduct, and statements towards critical minerals in supply chains, and there will be only minor differences in some actions taken in an *indirect* and *don't bother* approach. Another example, all studied companies combine *work with third parties* with other approaches, or those who established a *direct* approach for several minerals supply chains, can use an *indirect* approach for the other minerals with less priority for them. So, it can be said that companies choose a combination of governance mechanisms and practices that fits their goals and available resources.

Most studied companies develop responsible minerals programs as a part of their SSCM, and some companies report separately on their prioritized critical minerals (Tesla, 2021; Volkswagen Group, 2021a). In order to establish responsibility in minerals supply chains, a company can develop policies, standards, introduce management systems and create processes to identify priorities. Most companies follow OECD Due Diligence Guidance for Responsible Supply Chains of Minerals from Conflict-Affected and High-Risk Areas in defining their responsible mineral sourcing processes, including policies and management systems (Apple, 2021a) (Toyota, 2021a)

None of the studied companies were able to establish the same SSCM approach to different supply chains due to the "large number and diversity" of suppliers (Philips, 2021) or "a large and geographically dispersed supplier network" (Siemens, 2023). There are also different

maturity levels of SSCM practices for different materials, as there is no one-size-fits-all approach for such diverse supply chains, and often companies have to prioritize their activities based on "business importance, social and environmental considerations, position in the commodity market, and leverage" [B]. In the situation of limited resources, all companies used prioritization to choose their focus areas for SSCM practices, as an example of this:

- **Risk-based approach:** The prioritization process involves a comprehensive review of risks across different dimensions, including country or market, commodities, the severity and probability of breaches of the law, a company's influence, etc. (Volvo Group, 2021, Volkswagen Group, 2021b).
- **Based on product volume or costs:** A company can focus on selected suppliers with selection based on purchasing spend, the share of critical minerals in the product, etc. (Philips, 2021)
- **A mix of criteria:** A company can apply a combination of criteria, for example, "geopolitical risks in relation to labor and human rights or with significant impacts on the company (including companies surpassing a certain level in transaction amount and volume, companies recording low scores in the self-assessment, and companies affected by work environment issues raised by NGOs)" (Samsung Electronics, 2022), "Examples for specific risk categories are suppliers: based in higher risk countries, with high purchasing volume, that are requested from customers, with forced and compulsory labor risks and risk for child labor, with health and safety risks, mainly working in building business, providing products or services with a high carbon footprint, providing products relevant concerning responsible mineral sourcing" (Siemens, 2023).

The different priority levels can then be transmitted to the different approaches to minerals supply chains based on strategic objectives, resources available, and other factors:

- **Different levels of requirements for suppliers.** For example, IKEA has identified 4 levels of requirements that can be applied for the different suppliers: "IWAY requirements are based on a 4-step staircase model: Must, Basic, Advanced, and Excellent. IWAY Must and IWAY Basic are the minimum requirements that need to be in place for all suppliers and service providers who do business with IKEA. Together with our business partners, our ambition is to continually improve and develop beyond the minimum, to reach IWAY Advanced and IWAY Excellent levels" (IKEA, 2023)
- **Different SSCM practices.** Not only requirements can be different, but also overall SSCM practices applied to the specific group of suppliers, for example, Philips has 4 groups of suppliers with a different approach to each group: "Depending on supplier classification, we develop a tailor-made approach that supports continuous improvements through training and sharing best practices. For example, suppliers assigned to the status of (category I) only need to complete a self-assessment on an annual basis. Suppliers classified as (category II) are subject to an on-site assessment in addition to desk-based validation to verify their actual situation and develop an improvement plan. For (category III) suppliers, Philips takes immediate action to verify whether there is structural Zero Tolerance. If the conclusion gives rise to a structural Zero Tolerance, the supplier will be required to propose a mitigation and/or resolution plan and provide regular updates and evidence. Zero Tolerances will be internally reported to the procurement commodity leads, procurement leadership team, and corresponding business units" (Philips, 2023).

Overall, companies tend to focus on the priority minerals supply chains and priority suppliers as with so big and dispersed supply chains implementation of most SSCM practices, including SCV and SCT, is resource intense. Also, many companies with minerals supply chains are only

beginning their way towards SCV, and only a minority have already achieved some level of visibility over some minerals.

5.2.1. Indirect approach

Indirect is the most used approach among studied companies. It is based on the information-sharing mechanisms, and "contact with lower-tier suppliers is performed indirectly through another supplier, usually first-tier suppliers, who monitor or collaborate with lower-tier suppliers" (Gong et al., 2021; Tachizawa & Wong, 2014, p.651-652). *An indirect* approach can lead to the desired results if direct suppliers have the ability to adopt the standards of the focal company, and have introduced practices to transmit these standards to the low-tier suppliers. Tachizawa & Wong highlight "when first-tier suppliers adopt the same standard as the lead firm, they are able to gather sustainability-related information for lower-tier suppliers" (Tachizawa & Wong, 2014, p.651).

Following tools are used collect information from first-tier suppliers and through them get data on lower tiers of suppliers (a detailed description is provided in Appendix IV):

- Code of Conduct (CoC) with written expectations that suppliers will pass sustainability standards to their suppliers.
- Contractual clauses that oblige suppliers to pass the requirements to their suppliers.
- Questionnaire assessments allow to check how companies work with their suppliers.
- Audits that allow in-depth assessment of suppliers' activities and materials used, compliance with CoC, etc.
- Corrective action plans (CAP) to eliminate the identified gaps and shortcomings.

These actions allow to collect some data on supply chain actors, but the quality of information depends largely on the company's ability to check the compliance or the reliability of the information provided. If a company has thousands of suppliers just at the tier-1 level, checking their compliance may be resource-intense and unrealistic. And assurance of sustainable performance of actors on the lower tiers depends on the willingness of direct suppliers to cascade the requirements down to their supply chains and to ensure that all requirements are met. Testimonials of upstream producers show that there is a tendency of increasing pressure from customers, but now they are mostly requesting information without any actionable measures to influence suppliers: "Clients include specific clauses on sustainability performance in the contracts and they're going to check it on a regular basis during the contract. At the moment clients are just collecting data on compliance, but they're saying that as of this year, they've taken commitments and they need their customers to abide by those commitments. There's growing customer pressure on supply chains, but it's not too strong yet" [A].

Interviews show that the pressure is higher the closer supplier is to the downstream company. In the low tiers of supply chains situation can be different: companies see interest from their suppliers and regularly receive questionnaires to fill out. There are no strict requirements for standards on the sustainability performance of low-tier suppliers yet, but they are expected to be implemented shortly, as one of the upstream producers mentions: "Clients are asking mining companies the different certificates (RMAP, IRMA, ICMM). So far, they're just requesting, but they start to plan for procurement three years from now, and they ask if we plan to start the certification process. We think that in future they will be, most likely, demand either one or the other sustainability certification" [A].

Overall, all described practices cannot guarantee the implementation of sustainability practices and supply chain visibility due to the primary focus on direct suppliers and limited power to transmit it to the lower tiers. In an *indirect* approach, companies tend to focus on specific

suppliers rather than the entire supply chain. Existing tools are often limited by the information provided by the suppliers themselves, which may not be comprehensive or accurate. Audits can also have limitations as they capture information in one moment in the past or may have conflicts of interest [F]. The schematic picture of the indirect approach is provided below. It demonstrates that by choosing this strategy companies can capture limited, fragmented information about their supply chains, mostly on the closest tiers, and the most of sustainability risk data (e.g. the use of forced or child labor, pollution, low industrial safety, etc.) stay at an invisible level.

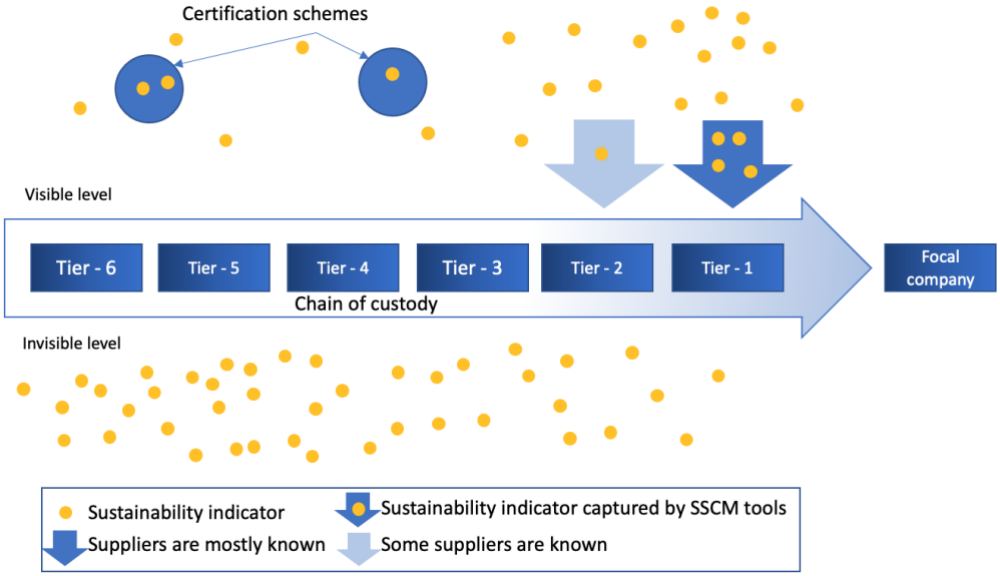

Figure 5-3. Simplified scheme of indirect approach

Source: own illustration

5.2.2. Direct approach

The studied companies were found to adopt a *direct* approach to managing their critical mineral supply chains. This was achieved through direct sourcing of these minerals from upstream producers and the establishment of supplier development programs aimed at improving the sustainability practices of midstream and upstream producers.

Among the studied companies, only two cases of **direct sourcing approach** were identified, Tesla and BMW. There are not enough examples to explain the factors that lead to choosing this approach, but it can be assumed that one of the reasons behind this is that both companies work in the luxury car market, and thus, they need to provide the best-in-class quality and sustainability performance. BMW uses a direct sourcing strategy to ensure material traceability and supply chain transparency: "We source all critical raw materials – such as lithium and cobalt, which are key raw materials for production of battery cells – for the current fifth-generation directly from raw material suppliers and make them available to producers of our current generation of battery cells. In this way, we can ensure traceability (mass balance) with regard to origins, as well as transparency around extraction methods" (BMW, 2023).

Tesla uses both **upstream supplier development programs and direct sourcing**, resulting in sourcing directly from mining companies more than 95% of lithium hydroxide, 50% of cobalt, and 30% of nickel: "the implementation of an OECD-aligned approach for cobalt, nickel, and lithium is underpinned by the following two pillars: 1. Direct sourcing from mining

companies: While cobalt, nickel, and lithium go through multiple processing steps by different companies, some of the more important environmental and social risks in this supply chain are present at mine sites. Direct sourcing from mining companies allows Tesla to engage directly in local contexts instead of having to rely on multiple midstream companies that typically sit between EV makers and mining. It also enables more transparent and traceable supply chains and better environmental and social data. All nine binding contracts include environmental and social requirements. 2. Direct local engagement: Building on direct supplier engagement, Tesla seeks to contribute to the continuous improvement of conditions in communities affected by operations in Tesla's supply chain, informed by engagement with local experts, community organizations, and civil society" (Tesla, 2021).

Direct is a rare and more resource intense approach that requires a lot of effort from the company. At the same time, it is a more comprehensive approach that includes mapping their entire supply chain and identifying the risks and sustainability issues at each stage. This requires collaboration with suppliers and stakeholders throughout the supply chain, as well as the use of technology and data analytics to track and monitor supply chain performance. The figure below demonstrates, that by approaching low-tier suppliers a company can achieve more visibility over its supply chains, but still, it does not mean that the company has established the full chain of custody on the minerals and the information about midstream suppliers can be limited.

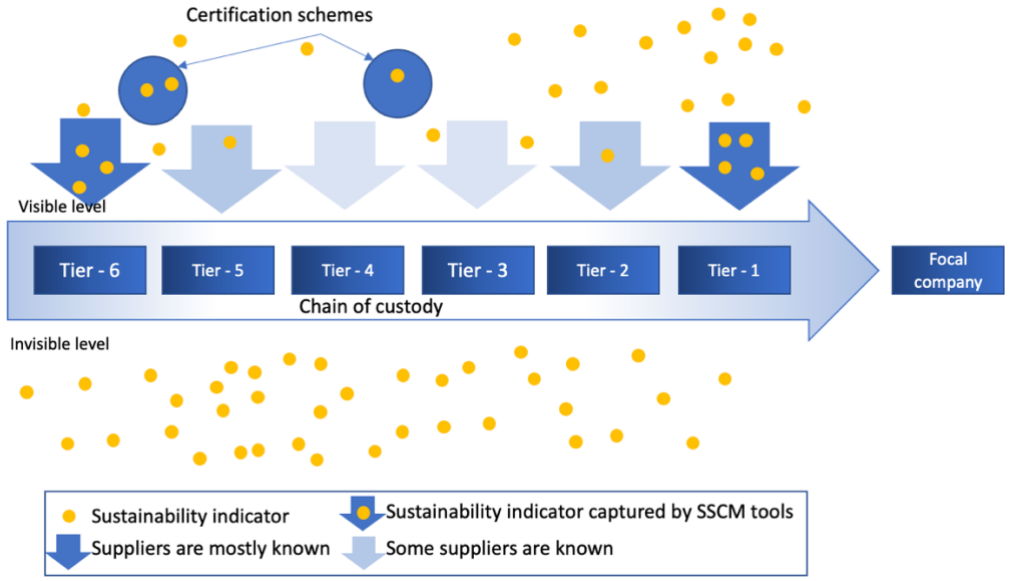

Figure 5-4. Simplified scheme of direct approach

Source: own illustration

5.2.3. Don't bother

This approach is used by companies that have limited power over suppliers, are less visible to the final customer, or have limited resources for the SSCM (Tachizawa & Wong, 2014), e.g. midstream producers, producers of equipment, or components of the final product. At the same time, Tachizawa & Wong highlight that companies that adopt the don't bother approach tend to follow the pioneer companies and adopt successful practices after they are tested (Tachizawa & Wong, 2014). In the case of minerals supply chains, the don't bother approach is used for the less critical materials that are less in the focus of stakeholders. This can also be a result of limited resources and not established SSCM practices for critical minerals when companies choose to

concentrate resources on the priority supply chains, test the approach, and expand it further on more supply chains in the future [D].

Don't bother approach hinder risks for companies. In case a company does not react to the stakeholder pressure proactively, it may face a situation where NGOs conduct investigations on violations in supply chains and blame a company for not being transparent or withholding low sustainability practices [B]. Another variation of this approach can be compliance with minimal requirements, when companies do not have an aim to establish SSCM practices, but rather ensure compliance with minimal resources [F].

This approach can also be applied to supply chains with a low priority level, as a company focuses its efforts on the prioritized supply chains. Among the studied companies, no one had a don't bother approach in SSCM, although section 5.1 shows that companies focus their efforts on certain minerals.

5.2.4. Collaboration with third parties

All studied companies use *collaboration with third parties* in addition to other governance mechanisms because the supply chain complexity and a high number of actors make it impossible for any company to deal with supply chain issues on their own [B]. Such third parties include industry and stakeholder associations, technology and service providers, NGOs, and government organizations.

Study results show that partnerships are the key to responsible minerals sourcing: "Nobody can solve such serious problems alone. In other words, when companies source raw materials from these areas, they must act in concert and develop universal standards together with civil society representatives" (Audi, 2021a). Another factor of collaboration is the overlapping of supply chains: "Supply chains overlap considerably in the electronics industry, with multiple manufacturers of finished products sharing the same subcontractors and parts suppliers. Accordingly, there are fears that the introduction of independent, company-specific standards for socially responsible management will cause confusion and constitute a significant burden on companies in the supply chain" (Sony, 2022), "the main advantage is the reduction of enormous labor costs that all supply chain participants have now in terms of reporting to their customers. Since everyone has their own reporting forms, companies have to fill them out every time anew for each client. Unification of labor costs for compliance has benefits for all" [E]. Another practitioner highlighted, that a collaboration approach when a neutral solution is created and several companies use it will also create "more trust, more credibility in the process" [B].

Main types of collaborations identified among studied companies:

- **Provision of tools and information for SSCM**, including standardized codes of conduct, suppliers' questionnaires, risk analysis maps, and databases. The most mentioned partners for this type of collaboration are Responsible business alliance (RBA, industry coalition), Responsible Minerals Initiative (RMI), an initiative of RBA, Drive Sustainability including Raw Material Outlook Platform, etc.
- **Third-party audit, certification, and verification of suppliers**. The most mentioned partners for this type of collaboration are RMI, and the example of the tool is Responsible Minerals Assurance Process (RMAP, an independent third-party assessment of smelters and refiners), IRMA, and RCS Global (suppliers audit & data platform).
- **Facilitation of stakeholder dialog**, shaping industry standards, joint testing of new technologies. The most mentioned partner for this type of collaboration is Global

Battery Alliance (GBA, stakeholder alliance), also there are several mineral-specific initiatives like Responsible Cobalt Initiative, Aluminium Stewardship Initiative, etc.

- **Technology development**. There is a big number of technology providers that companies collaborate in situations when they don't have the necessary technological capabilities inside the company. It can include different tools for supply chain mapping, risk monitoring, material traceability, etc.

Overall, companies heavily rely on third parties for their expertise and SSCM tools in specific minerals supply chains. However, in terms of SCV, there are limitations due to the focus on a specific part of the supply chain rather than a whole supply chain, the lack of appropriate tools and projects aimed at improving SCV, and systematically tackling problems in the supply chains and on the ground. Companies use third parties approach in situations, where they do not have specific capabilities, they want to use the unified approach to reduce the burden on suppliers, or they want to use collaborations as leverage to motivate suppliers in the sustainability data disclosure.

5.2.5. Approaches for SCV

Some companies do not clearly distinguish SCV and SCT. For the purpose of this study, all activities to gain knowledge on the supply chain participants are considered SCV activities, and all activities to share information on the supply chain participants with stakeholders are considered SCT activities.

Companies in the scope of this study use similar approaches to achieve SCV. In general, supplier assessment for tier-1 is used to identify risks connected with critical minerals. In case of such risks are high, selected suppliers undergo more detailed due diligence processes, including internal and third-party audits. Companies ask their suppliers to provide information on their suppliers and ensure that critical minerals come from certified refiners and smelters. To collect data from suppliers, questionnaires are used [A]. Tesla reports that the company uses its own Know-Your-Supplier Questionnaire for supply chain mapping of batteries used in their products (Tesla, 2021).

The same approach is used by many companies, for example, Sony (Sony, 2022): "Every survey year, Sony checks each business group to see if there is any possibility for the four minerals being used in its products. Sony further looks for the presence of the four minerals in the products of the identified business group that are manufactured or outsourced for manufacturing by Sony in the survey year and identifies target products. The survey is conducted using the RMI Conflict Minerals Response Template (CMRT), the industry standard, and target suppliers are asked to participate by filling out a survey response for each product concerned. in order to identify the smelters or countries of origin for the procured minerals concerned. The smelters indicated in the survey responses are then carefully compared to the RMI smelters list". Another example is Philips (Philips, 2023) "Given the large number and diversity of Philips' suppliers, Philips focuses its efforts on a group of first tier priority suppliers and works with them to identify the smelters in their supply chain. Philips request them to submit information to Philips using the CMRT[1]. The information submitted by priority suppliers includes information gathered by those suppliers about the smelters identified in their own supply chains. The information has been used by Philips to assess the due diligence efforts implemented by priority suppliers and to identify smelters in the supply chain. Philips made responsible sourcing of minerals a supplier contract requirement".

[1] Conflict mineral reporting template by RMI

This approach also results in rather vague reported **key performance indicators.** A review of public reports showed that companies do not have strong pubic KPIs on SSCM or SCV. Most of the indicators used by companies are processes based (e.g. number of activities) with only several result-based indicators (e.g. % of responsibly sourced minerals). None of the indicators used by studied companies provide a holistic picture of the state of SCV in the company. Examples of KPIs that companies use to evaluate their SCV activities are provided below:

- Number of identified suppliers (Apple, 2022c; Stellantis, 2021);
- Audited/assessed suppliers, in absolute number and % from a yearly spend on direct supply base (Tesla, 2021), purchase volume in a specific region (ABB, 2022; Toyota, 2021a), or direct material spend (Volvo Group, 2021);
- A number of companies completed the RMI's Risk readiness assessment (Apple, 2022c);
- Number of verification activities performed (IKEA, 2022; Stellantis, 2021);
- Number of supplier employee interviews conducted (Tesla, 2021);
- Number of action plans agreed by the suppliers (Stellantis, 2021);
- % of responsibly sourced key minerals (Apple, 2021b).

By gathering data from suppliers companies try to establish a comprehensive **supply chain map** for specific products. Because of the big size of the supplier base, companies need to focus on collecting information on sub-suppliers of specific products and/or from specific areas (e.g. high-risk and conflict-affected areas). "The first step is to cluster potential and active supplier locations according to country-specific and regional environmental and human rights risks. The standardized risk roadmap of the Responsible Business Alliance (RBA) serves as the basis for this, as well as other data sources that focus on supply chain risks" (BMW, 2023). For different supply chains mapping can be more or less complicated: one practitioner mentioned that for half of the targeted supply chains, it was possible to create a supply chain map up to the raw material level, for the rest they got stuck somewhere in midstream [B].

One of the ways to get information for supply chain mapping is to include the obligation to provide information on sub-suppliers in the contracts with suppliers. For example, Volkswagen is using "contractual requirements for all new suppliers since 2020 to regularly disclose details of sub-suppliers up to the mine site" (Volkswagen Group, 2021a). At the same time, the company reported that only 4 suppliers have provided this information in 2021, so the process is still in the development phase. Apple requires their suppliers "to map their Supply Chains for Relevant Minerals and Relevant Materials", and "shall communicate the following Supply Chain mapping requirements to their Supply Chains and ensure the following requirements are met by Processors, including their traders (if any) and sub-suppliers back to the Source or Origin in their Supply Chains" (Apple, 2022b). The same obligation may be included in the CoC, for example, "Suppliers are expected to work with their sub-suppliers to establish traceability of Conflict Minerals to the smelter level and encourage the use of a standard reporting process (e.g. the Responsible Minerals Initiative Conflict Minerals Reporting Template)" (Caterpillar, n.d.). In case of the suppliers are unwilling to provide information for supply chain mapping activities, companies can terminate the relationships with them (Apple, 2022b).

Supply chain mapping activities are not reported explicitly by companies, but some of them state that they are working on this, thus it is difficult to evaluate the progress of these activities. Also, it is hard to evaluate the effectiveness of SCV activities. If the identification of smelters is based on self-reporting and a small number of audits, then data may not be comprehensive, and the company may not be able to identify all actors in their supply chains.

Overall, several tools are commonly mentioned among companies: standardized or tailored questionnaires to identify the presence of minerals, data requests to selected suppliers to provide data on their sub-suppliers up to smelters and refiners of selected minerals, including their certification status. Some companies go beyond the refiners to establish concrete mines of minerals origin. By conducting supply chain mapping a company can get more information about suppliers, and thus, capture more sustainability indicators on its supply chain. But additional tools are needed to capture the increased information about suppliers and sustainability indicators, and companies start to implement advanced digital tools for this purpose.

Digital platforms for supply chain mapping and sustainability data collection

Digital platforms are increasingly being used to enhance supply chain risk monitoring and management. A digital platform is "a digital space that provides facilities for users to collaborate, interact or transact digitally" (Anshari et al., 2021). These platforms enable the real-time collection of data from various sources, enabling more precise and prompt evaluation of supply chain risks and opportunities. Using digital platforms from third parties can allow companies to optimize resources on supply chain data collection. Also, it can make the process more efficient: suppliers only need to provide data once to the platform and then it can be used by multiple buyers. Examples of the digital platforms for **supply chain mapping** are Vine (*RCS VINE*, n.d.), Resilinc (Resilinc, n.d.), Sourcemap (Sourcemap, 2023).

Among the studied companies Volkswagen and Stellantis are implementing RCS solutions for SCT. Stellantis has created a "multi-material supply chain program covering battery materials including cobalt, lithium, graphite, and nickel" in partnership with RCS Global. As a part of the partnership, RCS "completed 40 on-site audits of companies at every tier of Stellantis' cobalt and lithium supply chains", identified more than 550 suppliers and 14 mineral origin countries (Stellantis, 2021). Stellantis also use the Vine platform from RCS that allows a company to achieve SCT and meet regulatory demands: "With Vine, we are able to visualize and get a quick overview of our complex battery supply chain step-by-step all the way to the mine sites. This data we can turn into knowledge to help inform prioritization, supply chain management, and stakeholder engagement" (Stellantis; *RCS VINE*, n.d.).

By analyzing early warning signals and alerts, digital platforms help companies to proactively manage and mitigate risks in their supply chain. One of the examples is Ulula. Ulula's approach to supply chain transparency involves empowering workers and communities in the supply chain to voice their concerns and feedback about working conditions and violations. It provides a platform for companies to collect and analyze data on worker welfare and community impact through surveys, hotlines, and other feedback channels, providing transparency on the situation on the ground. The platform allows workers to anonymously report any issues related to labor rights, working conditions, and environmental impacts directly to the companies they are supplying to. This information is then verified and analyzed by Ulula's team of experts, who work with the companies to develop corrective action plans and support community development programs (Ulula, 2021).

Some digital platforms are now integrating **AI-powered risk identification tools** in their work. These tools work by analyzing data from various sources, including supplier assessments from various sources, news articles, social media feeds, and other public and private data sources. The algorithms are trained to find patterns, trends, and irregularities in the data that may point to potential risks or opportunities. The AI-powered risk identification tools allow enhanced risk management, and greater efficiency and accuracy in identifying potential risks. However, the main challenge is the accuracy of the data, as the tools rely on large amounts of data to make

predictions. Unreliable data may result in erroneous forecasts and decisions. Also, there is a risk that companies may become over-reliant on technology and overlook the importance of human expertise and judgment in identifying and managing supply chain risks. To approach these challenges, the company uses AI for the early identification of risks, but then still conducts in-depth assessments ans on-site checks for the suppliers with potential risks (Siemens, 2023).

AI-powered tools are the most common in the automotive industry. For example, BMW uses it to identify risks for indirect suppliers: "The BMW Group operates an AI-based early warning system, for example, which analyses vast amounts of data from online media and social networks in over 50 languages to alert us to suppliers who may be breaching human rights or environmental standards. This way, we can detect any potential sustainability risks in the supply chain early on" (BMW, 2023). Volkswagen and Audi also use AI tool developed by start-up Prewave to monitor sustainability risks: "this system aggregates publicly accessible news from around 150 countries. The AI understands the content of the reports and classifies them based on any suspicion of potential sustainability violations. In the case of criteria from the "Social" category, for example, the focus is on labor law developments, unrest in the workforce, child labor, and discrimination in the workplace. Audi is automatically informed whenever a potential sustainability risk begins to develop. The matter is scrutinized in detail within the company, and action is taken as appropriate" (Audi, 2021b, Volkswagen Group, 2021a).

Overall, digital platforms can help companies to process significantly more information on the sustainability performance of their suppliers with fewer resources, but it does not replace the existing systems of supplier assessment. The Figure below shows that by conducting supply chain mapping a company can get more information about suppliers, and thus, capture more sustainability indicators on its supply chain. Also, the more suppliers with their geographic locations are identified, the more data on sustainability risks the company can get just by understanding the supplier type (miner, smelter, etc.), materials used, and location (e.g. conflict-affected and high-risk areas). By using available digital tools companies are able to collect this data and use it in the decision-making process. Still, these SCV tools do not allow to establish the chain of custody for the minerals and identified suppliers at an invisible level that can still enter the supply chain at several points.

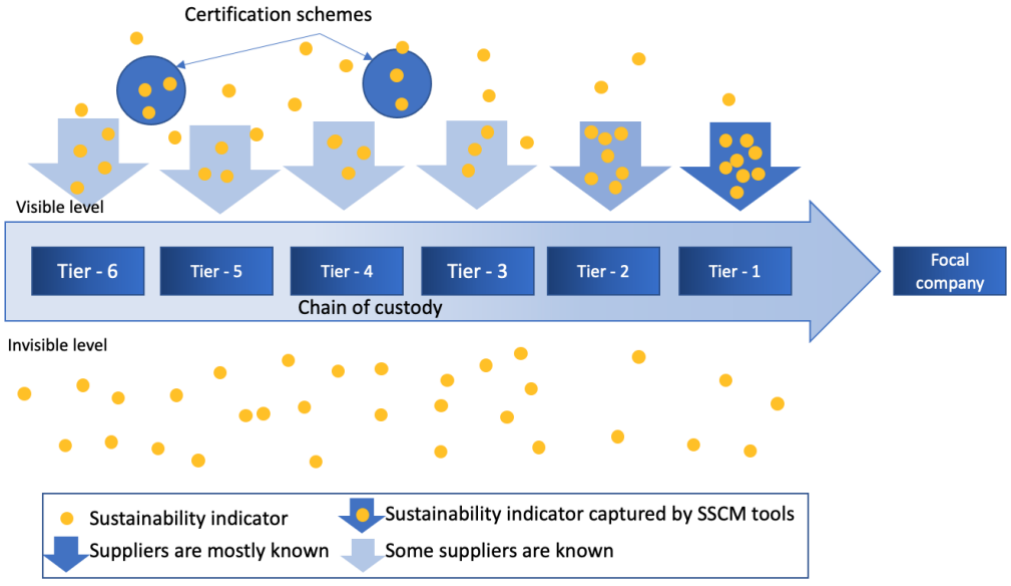

Figure 5-5. A simplified scheme of SCV applied to SSCM
Source: own illustration

5.2.6. Approaches for SCT

Among the studied companies, several approaches to SCT can be identified:

- Compliance level: the company only reports on activities towards SCT if they are legally required, e.g. publishing conflict minerals reports according to Dodd-Frank Act, providing general information on the approach to minerals SSCM, including supplier selection and collaboration (reporting on responsible minerals sourcing); etc.
- Basic transparency: companies report separately on SSCM for different minerals that allow to have a basic understanding of specific supply chain characteristics; the company publishes a list of suppliers/smelters; etc.
- Advanced transparency: companies publish information on midstream/upstream actors in the supply chain, share traceability and sustainability performance data; etc.

Reporting on specific minerals is used by most companies towards conflict minerals, but some companies go beyond that to provide raw materials reports on other minerals, for example, BMW, Tesla, and Volkswagen.

Published lists of suppliers (tier-1 or midstream - refiners, smelters, processors) allow to get information on the name and geographic location of these companies, but without additional research on them, this information does not lead to any conclusions. An exception to this is Tesla, which publishes a list of suppliers with information on their sustainability and life-cycle assessment (*Figure 5-6*).

Supplier	Material	Country	Type	Independent External Sustainability Assessment[1]	Life-Cycle Analysis (LCA) Completed[2]
Albemarle	Lithium	Australia (mine); China (refinery)	Integrated Mine Site + Refiner		
Livent	Lithium	Argentina (mine); China, USA (refinery)	Integrated Mine Site + Refiner		
Ganfeng	Lithium	China	Refiner	N/A[3]	
Yahua	Lithium	China	Refiner	N/A[3]	
Guizhou CNGR	Cobalt, Nickel	China	Refiner		
Hunan CNGR	Cobalt, Nickel	China	Refiner		
Huayou	Cobalt, Nickel	China	Refiner		
Glencore Kamoto Copper Company	Cobalt	Democratic Republic of Congo (DRC)	Mine site		
Glencore Murrin Murrin	Nickel	Australia	Integrated Mine Site + Refiner		
BHP Nickel West	Nickel	Australia	Integrated Mine Site + Refiner		
Prony Resources	Nickel	New Caledonia	Mine site		
Vale	Nickel	Canada	Integrated Mine Site + Refiner		

[1] Independent external sustainability assessments included: Initiative for Responsible Mining Assurance (IRMA), the Responsible Minerals Initiative (RMI) Responsible Minerals Assurance Process (RMAP), and/or the International Council on Mining and Metals (ICMM) Performance Expectations, Towards Sustainable Mining (TSM)
[2] This column refers to LCAs conducted by the supplier (not Tesla).
[3] There is currently no industry-wide 3rd party audit program for lithium refiners.

Legend

	Completed
	In progress / planned / commitment made
	No commitment / undisclosed

Figure 5-6. Example of the published list of suppliers and sub-suppliers

Source: (Tesla, 2021)

Traceability

According to RMI, traceability is "the ability to follow the trail of minerals along the supply chain by monitoring and tracking chain of custody" (RMI, n.d.). This means that the mining site of origin of the raw material can be established. Chain of custody "provides a record of the

sequence of entities that have custody of minerals as they move through a supply chain", which includes documentation such as mine origin certificate, transport documentation, export and import records, and factory receipts (RMI, n.d.). Traceability projects demand collaboration with supply chain partners and external stakeholders like industry associations and technology developers (Audi, 2023; BMW, 2023).

There are two approaches to traceability: down-up based on historical data or up-down based on real-time data. The down-up approach includes collecting data from suppliers using questionnaires and audits to identify the origin of the material foing from higher to lower tiers. Another way to establish traceability requires digital technologies: when at the mining site the digital mark of one batch of minerals is created and then traced through the entire supply chain to the end customer. Technology-enabled traceability is not a substitute for existing traceability schemes, but rather an addition that allows to collect more data with fewer resources and time: "Traceability platforms for minerals is more of a supplement to existing standard schemes. It's about the fact that you can put everything on one platform, it helps to implement what the standards set. Now there's more understanding that it's very difficult to collect and verify suppliers' data without a system or platform to keep track of it all" [A], "Traceability is something that adds value to the system by tracing goods, but there is still a need you to verify the actual working conditions and human rights impacts on the ground" [F].

Blockchain-based traceability has grown attention in recent years as blockchain technology applications have been piloted in different industries for tracking of goods across the supply chain. Blockchain-based traceability refers to the use of blockchain technology to track and verify the movement of minerals from the point of extraction to the end consumer, establishing its chain of custody (see more detailed explanation in section 3.3.). This technology allows for the creation of a secure, tamper-proof ledger of transactions, providing transparency and accountability throughout the supply chain (RCS Global, 2017; ReSource, 2023). Among the studied companies, there are several blockchain-based traceability pilots mentioned. For example, Tesla is a member of the Re|Source consortium that works on establishing the first end-to-end blockchain-enabled tracing of cobalt material from the company's supplier in the DRC to the Gigafactory Shanghai (Tesla, 2021).

The benefit of blockchain-based traceability is the opportunity to get near real-time data on the movement of materials and immediately detect if the materials from unknown sources enter the supply chain (ReSource, 2023). However, there are also limitations to the use of blockchain-based traceability in critical minerals supply chains. One challenge is ensuring that all parties in the supply chain participate in the system and accurately report information. Without full participation, the system may not provide a complete picture of the supply chain and could be vulnerable to fraud or manipulation. Also, the technology is still relatively new, and only several pilots were conducted in recent years, and blockchain-based traceability projects in minerals supply chains are only starting their entrance to the full-scale implementation stage (RCS Global, 2017; ReSource, 2023). As industry participants share, that creates a barrier to entering such initiatives: "All the blockchain traceability solutions are in pilot stages now. You don't know which ones you should trust, which one is the most advanced" [D]. A lot of challenges still have to be solved, and technology should mature.

Digital product passports

Several new policies (Battery Regulation, EU Circular Economy Action Plan) require the development of digital products passport (DPP). DPP is a unique electronic record that contains information about product characteristics that are accessible online and can be used to provide essential product data to different stakeholders (Circularise, n.d.; Proposal No 2019/1020,

2020). Digital product passports are designed to support the transition to more sustainable products by collecting and providing information on product/material origin, sustainability indicators, recycling properties, etc. It is expected that product passports will be introduced in the next five years in several industries, including electric vehicle batteries, textiles, and construction products (*Circularise*, n.d.). DPPs can be used to track a product's entire lifecycle, from raw material extraction to disposal and collect detailed information about the battery's environmental footprint, including the type and origin of raw materials used, the manufacturing process, energy efficiency, and end-of-life management (*Digital Product Passports (DPP)*, n.d.).

Several existing initiatives are working towards developing battery passports. For example, the World Economic Forum launched the Global Battery Alliance in 2017, which aims to create a circular battery value chain and includes a workstream on DPPs. The Alliance is working with industry leaders, policymakers, and NGOs to develop a global standard for DPPs, which will provide transparency and accountability in the battery value chain. The Battery Pass project is another example of a digital product passport for batteries. The project, launched in 2020, is a collaboration between several European countries and aims to develop a standardized digital passport for batteries, including electric vehicle batteries. As one industry player mentions: "The battery passport has the potential to become a key tool for empowering and enabling responsible and sustainable value chains. If it's done properly we will get a new level of transparency along the supply chain and we will see a drive and sustainability performance through that increase in transparency" (RCS Global, 2023).

In conclusion, SCT tools allow to collect more data by making information on the supply chain publicly available and by establishing a chain of custody. This allows better identification of where and how many materials from the invisible level enter the visible supply chain. By implementing digital product passports, all information about suppliers, their sustainability indicators, and the chain of custody can be gathered in one place and communicated to stakeholders (*Figure 5-7*). However, all described tools only provide more comprehensive and high-quality information on supply chains, but they do not directly work at the invisible level.

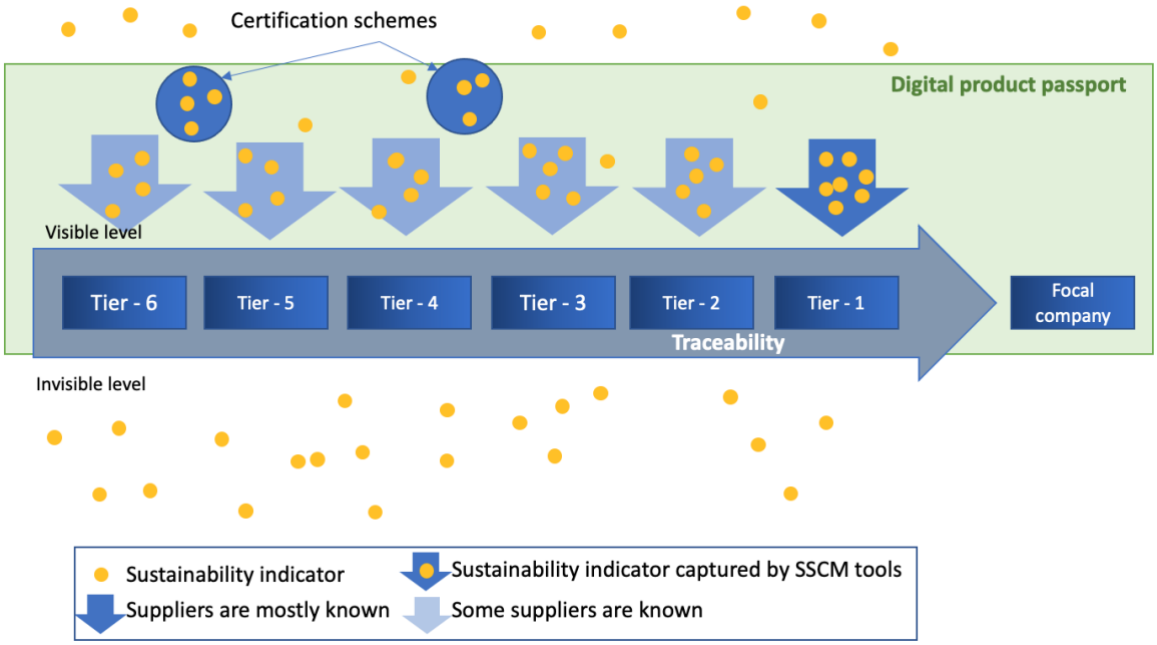

Figure 5-7. Simplified scheme of SCT applied to SSCM

Source: own illustration

5.2.7. Challenges of establishing SCV and SCT

Practitioners identify numerous challenges that prevent the attainment of visibility and transparency in multi-tier supply chains. Some of them are connected with the process and the results of SCV/SCT, but some of the challenges represent the more systemic problems that will become visible if the SCV/SCT will be established.

Consequences of transparency. The issue of transparency in supply chains has created a paradoxical situation for companies. On one hand, NGOs and other stakeholders are calling for greater transparency and disclosure of supply chain practices. On the other hand, when companies do become more transparent, they often find themselves subject to increased scrutiny and pressure from these same stakeholders. In some cases, this has led to a situation where more transparent companies are actually suffering more than those that keep their supply chain practices secret: "If a company doesn't comply (with due diligence requirements), then it may be fine, but if a company comply then it may be in trouble because it has problems in the supply chain. And if it does not take any action against this or that issue, then it is also going to be liable" [F]. One possible explanation is that NGOs and other stakeholders are simply using transparency as a way to push for greater accountability and change. By calling for greater transparency, they can bring attention to supply chain issues and pressure companies to take action. However, when companies do become more transparent, NGOs may use this as an opportunity to demand even more disclosure and action, leading to a never-ending cycle of pressure and scrutiny. The same is true for SCV: if a company has achieved visibility, in the eyes of stakeholders it immediately becomes responsible for the low practices along the supply chain and being transparent about it to stakeholders.

Stakeholders' pressure may have the opposite effect among targeted companies and lead to an unwillingness to be transparent about supply chains. When companies are asked to be more transparent on their supply chain, there is a time lag between achieving visibility, identification of issues, and corrective actions that can take months. Stakeholders sometimes want to penalize a company for the issues, and not wait for the issues to be resolved. This discourages companies from being proactively transparent: "Some NGOs are really trying to focus on creating positive change, but some others are only focusing on putting companies out there for name and shame campaigns" [B].

GBA expert confirms this: "Companies have a fear that publishing excessive information about the supply chain would increase reputational risks for them- customers might stop buying products because of negative reactions to information about suppliers". Sustainability manager of a downstream company agrees that fully visible and transparent supply chains can lead to the negative reactions: "Companies are being requested to be externally proactively sharing visibility and so being transparent about the supply chain visibility, but often those who do that end up being penalized. You can't ask people to be open and then immediately come and penalize them because then it fosters the culture of people not talking unless they are really forced, and it will also not foster the movement of change that we want to create with this transparency. If we want transparency, it needs to identify what are the gaps to be able to address them, it's not to be able to be pointing fingers at companies" [B]. Moreover, there are issues that companies can not solve: "There are some things that require significant changes as the public sector reforms and other structural changes on the governmental level. At the moment, you take these as things that you cannot move. You have to decide what you can change and what you cannot" [F].

SC actors can hinder the development of SCV/SCT if its results may be used for politically motivated purposes. As one interviewee says: "I think one potential negative impact of having full visibility of supply chains: we live in a world where there's a lot of politics and antagonism. The minute you have visibility there will be a will from many actors to say that now we have

this from Country X, and we don't want anything from Country X in our supply chain. That is a powerful tool to exclude people, and at the end of the day, it would not create a better world for anybody, not for those who are in regions that would be excluded" [B]. Also, there may be no alternatives to the critical minerals in the amount that is required for the global decarbonization goals, so political will can also promote the fact that in the absence of transparency, all available sources of minerals can be used [F].

The complexity of creating collaborations. Collaboration is the key to the development of new solutions, but collaboration is the major challenge as it requires a lot of coordination and often there are legal barriers to collaboration. Among legal factors that limit the exchange of information are anti-trust laws and nondisclosure agreements (NDAs) (Volkswagen Group, 2021a). Founder of the traceability technology provider Minespider discusses: "It's very important to understand that many companies are not used to collaborating along a supply chain. This is because usually you are used to competing and differentiating from your competitors and not collaborating with them. Sometimes it's not even allowed from a legal point of view, so people and companies are very cautious to share insights or ingredients of products: competitors make pick it up and then have a competitive advantage. Companies are used to signing NDAs and keeping things disclosed, and this is something that contradicts transparency" (Mines, 2021).

Even if some companies in the supply chains want to collaborate for SCV, others may hinder this process. According to the downstream producer's testimonials "Sometimes our supplier is willing to share the data but their suppliers have confidentiality agreements and are not allowed to share anything. We have industries today that are fully based on confidentiality. For you to be a player in that industry you need to sign non-disclosure agreements otherwise you can't make business" [B].

Systemic problems of supply chain design. The problem lies deeper in the roots of supply chains: supply chains as they work now are not designed for visibility. The competitiveness of many actors depends on the information disbalance by protecting commercial information about suppliers, sources of products, and specific characteristics of the deals [D]. As was shared by an interviewee from GBA, "The process is complicated by different schemes to work with suppliers, which is commercial information, and companies are interested in keeping it private" [E]. There are also a big number of middlemen and middle actors that are present in all supply chains and have only an intermediary function, connecting different supply chain actors. As the sustainability manager of downstream producer states: "Supply chains are not today set up for companies to start asking for visibility. You buy things on the market and you're not even asking where this is coming from, and there have been multiple aggregations. Almost every supply chain in the world has traders and the minute you hit a trader you have a problem: they create blocks in information flow both ways. There are a lot of middle actors and no efficiency. It's just the sub-optimized at all levels and I think the minute we are able to see supply chains, we will start asking ourselves questions on how we can make it more efficient, more resilient, addresses social and environmental issues, and actually connect the ends of the supply chain." [B] This opinion also highlights the significant threat: if visibility will lead to more efficient supply chains with fewer tiers and actors, the potentially excluded actors (traders, middlemen) will resist it with all their power. Many actors are reluctant to the information disclosure: "Anti-trust mechanisms are used as an opportunity to keep information out" [E].

Another systemic problem is the limited influence of the sustainability function over the buying processes, as both corporate functions have their own goals. As an example, the sustainability manager of midstream producer shares: "We have a very complicated diverse supply chain with more than 20000 suppliers all over the world just in tier-1. On the group level we provide

frameworks, we provide strategies, targets when necessary, reporting system, including sustainability reporting and reporting of our raw materials. Everything is governed by the group but managed locally" [C].

Supply chain dynamics are among the main challenges for establishing SCV/SCT (BMW, 2023). Supply chains are extremely big and diverse with tens of thousands of suppliers on the tier-1 level, and several times as many in other tiers. Supply chain actors can enter or quit the relationship, merge and dissociate, change partners, etc. which leads to the supply chain dynamism. The sustainability manager of downstream producer highlights this problem: "Supply chains are extremely dynamic: they change every hour, every day. That's why we are not sure that we will ever be able to have total visibility of supply chains. We have this vision of having supply chains mapped, but the minute you have it mapped it has changed already. So how to manage that is a big question: the more dynamic, the less control" [B].

Supply chain complexity and diversity, meaning the size of supply networks, geography, a big number of tiers, middlemen, and other supply chain characteristics, require a tailored approach to different actors. To ensure a completely new level of visibility and transparency, all actors will have to change their practices and the motivation for that should be tangible: "You need a very strong incentive to allow supply chain transparency. Unless there is a regulation, unless there is an alternative benefit for the suppliers, it's really hard to get that transparency" [D]. Another aspect is different technology and knowledge level in the different parts of the supply chains that also complicates the supply chain processes: **"**existing network has two parts which don't want to cooperate so much. There's part of the world that will only accept old-fashioned Excel and on-site audits, and that will stay that way for a long period of time. We need to acknowledge that there are different parts of the world that are crucial to this part of the supply chain or this supply chain that may be reluctant" (RCS Global, 2023).

The complexity and diversity of the supply chain pose a significant challenge for companies, and as a result, some opt for a simplified approach of claiming mineral sourcing only from large-scale mines with all required sustainability certifications. However, this is not a solution to the problem but rather a dismissal of it: "It can be seen as the easiest choice to only work with large-scale mining (LSM) sources. But in the case of cobalt in the DRC, ASM-sourced minerals can end up in the supply chains of LSM companies. Saying that cobalt sourced from the DRC is therefore "ASM-free" cannot be considered credible. It's just a way for downstream companies to look away and not face the real issues. It doesn't replace the need for proper monitoring on the ground and the need to look at the bigger picture and formalize ASM overall, because this is the only way we will progressively reduce the risks and improve overall mining governance. This is why we need downstream companies to commit to sourcing from ASM and support formalization efforts" (PACT, 2022).

Additional resources will be needed for both implementation of new practices in the supply chains and further actions to improve suppliers' practices. As a result of the supply chain complexity and tailored approach described above, the implementation of SCV and SCT will require significant resources [D]. Technology provider RCS Group shares: "The supply chain complexity is a core challenge to organizations that want to improve transparency and ensure that responsible sourcing is occurring in the supply chain. Complexity obscures risks in supply chains and it also means that it's very hard and in fact resource intensive for individual organizations to engage with sub-suppliers, assess performance, measure their performance, document and then communicate and report on this" (RCS Global Group, 2022). This is also confirmed by downstream company: "if somehow we manage to get full supply chain transparency and we're able to monitor all of our sustainability KPIs, we're going to uncover things that we are not going to be able to ignore. It might require us to go to the site, run an

audit, and set up some corrective action plan that we will have to monitor over time, so it becomes a much bigger correction activity than what we're currently doing. So we will need to secure that we actually have the resources to process the additional work" [D]. Also, there is still no understanding, of how these additional investments will be shared between participants, especially in the situation of supply chain diversity when different actors have significantly different resources available: "The biggest questions are that one, who is going to pay for that, and two, who is going to solve the issues found? There are liability questions that are quite complex and that's an ongoing debate" [F].

Another problem is that most of the suppliers serve several customers, and usually several focal companies "share" the same supply chains. It is a challenge to make the requirements for suppliers aligned and it requires a lot of collaboration, but at the same time, it is the opportunity to share the investment in the new tools [A, F].

The different maturity levels of SSCM practices. Establishing visibility for different supply chains can have different levels of barriers. There are more developed tools for SCV and SCT of 3TG and cobalt and less developed resources for other minerals. This leads to the SCV/SCT being less common in other minerals supply chains, and also companies are finding it more challenging to include other minerals in their SCV/SCT activities [D]. Another challenge is following this one: companies are not sure that for less popular supply chains it will be even harder to involve suppliers in SCV/SCT activities and the whole process will not be effective in terms of invested resources/outcomes. They prefer to focus on the priority supply chain to test how to approach all issues and challenges, and then expand it to the other minerals [D].

SSCM practices also differ significantly depending on the tier: "Historically, most responsible sourcing programs focus on preventing and responding to forced labor exploitation risks in the most accessible and visible levels of their supply chain, known as their "Tier 1." However, many risks of forced and child labor exist beyond Tier 1, where companies lack the tools and visibility to identify them. At these deeper levels, the risk increases substantially. While strong efforts have been made, especially in the extractives industry, to create end-to-end traceability, these solutions remain small-scale and inapplicable to multiple industries" (ELEVATE, n.d.)

As every supply chain has its own best practices, collaboration groups, and available tools for SCV/SCT it is difficult for companies to understand where to start, what are the best practices at the moment, and how developed are technologies available on the market. Sustainability manager of midstream producer notes: "The main challenge right now is to understand what the best practice is because it's very difficult to find the best practice that is relevant and that is really the best. Many companies use very different solutions. We talk to many third-party suppliers of different IT systems, databases, and other applications that might support corporates in their sustainable supply chain work, but it's very difficult to say what is relevant and what will work for us" [C].

Lack of standards for sustainability indicators in supply chains. A part of the SCV/SCT process is the collection of sustainability-related data from suppliers and the due diligence process. At the moment, there is a lack of clarity on supply chain due diligence requirements. From all conducted interviews it is clear that one of the main drivers of SCV/SCT is changing regulations that will demand new approaches for supply chain due diligence from companies. At the same time, there is a lack of clarity on what will be demanded in particular: indicators, calculation requirements, data collection and verification, etc. Sustainability manager of the downstream company comments: "I would really like to see more and clearer regulations from decision-makers, from politicians. The coming European legislation, the CSRD, is still in draft form, so it's a bit early to say that this will really be a proper guideline" [C].

Due to the complex nature of the supply chains, data standardization is important, especially for the indicators that are difficult to measure, for example, compliance with human rights and the prevention of child labor. These standards should be simple and digestible by suppliers with a low level of technological development. Creating the commonly accepted framework is one of the biggest challenges (RCS Global, 2023). GBA expert confirms that: "We need digestible standards for measurements, a common approach accepted by the whole industry" [E].

5.2.8. Connections between SCV, SCT, and SSCM

In this section, different statements from practitioners are explored to understand possible connections between SCV, SCT, and SSCM. In some cases, there is no clear distinction between SCV and SCT, as some companies tend to use both terms to describe the same process without highlighting if it is internal knowledge (visibility) or external (transparency). Also, some practitioners had made statements on the traceability as a tool to achieve SCV and SCT, they were included in this section as well. Overall, this section introduces some opinions on the connections between the concepts that will be further discussed in section 5.3.1.

SCV is not the end goal, but it is an essential requirement to achieve SSCM goals and create a positive impact: "You cannot control what you cannot see. Visibility is just beginning because it was never the end goal. You have to see in order to act and act in order to make an impact. So visibility has to be connected with execution because that's ultimately the goal is to get the performance where you needed" (SupplyChainBrain, 2022). SCV helps companies to identify hotspots that can lead to the targeted actions to improve the sustainability performance in these hotspots: "once you know where the hotspots are you can take action. You need to go down to the ground and drive the change locally. There is no law of nature which is forbidding to produce cobalt without child labor, it just needs to find the mechanisms for how we can help those local societies to make their living without unacceptable practices" (RCS Global Group, 2022). The converse statement is also confirmed by practitioners: "We want to secure sourcing of raw materials into our products in a more responsible way considering social and environmental components, but this is a supply chain where we have almost no visibility and no clear picture on how to approach this task" [B].

The same logic can be applied to SCT and traceability: "Traceability is a very process-focused subject. There's nothing environmentally responsible or indeed socially responsible about traceability but it is sort of a backbone that enables you to build on top of that social or environmental metrics and also actions" (Norton, 2021). This is also confirmed by the testimonial of a downstream producer about SCV: "I think visibility will be an important enabler to really create a positive impact in supply chains. At the moment companies are not able to see people in their supply chains, environmental degradation, etc. When someone illuminates their supply chains, they will be able to prioritize and say this is happening, it should not be happening" [B]. The same view is shared by other downstream producers: "Transparency is the fundamental requirement for managing the supply chain in accordance with our standards" (Audi, 2023), «Ensuring compliance with environmental and social standards in the supplier network is the declared aim of the BMW Group. Creating transparency around far-reaching, dynamic supply chains and making goods flows traceable are the most important requirements for this» (BMW, 2023). There is also another perspective on the connection between SCV and SSCM: you do not always need to have visibility over your supply chain to know that there are most probably sustainability-related risks with some of the minerals that you use [F]. It may not be reasonable to wait for the good state of SCV to begin to act.

SCV and SCT practices should fit into an established SSCM system: "A key point is that traceability – knowing where your minerals come from – is only one component of due diligence. Due diligence is a process of verifying your suppliers, where and how your minerals

were mined, transported, and traded, and under what conditions, and then assessing and addressing risks. Traceability is only the start" (PACT, 2022). SCV and SCT can also be a bottleneck in the realization of other sustainability goals of a company, for example, decarbonization [C], (Apple, 2022a).

As was mentioned in section 5.1, SCV and SCT are developing as the result of stakeholder pressure, but at the same time, SCT can raise pressure on more stakeholders, making them see things that were hidden for a long time and make it difficult not to make actions: "traceability allows you to understand where things are coming from and then to take action in the places that are most required in your supply chain. We're really very far away from the people that are often responsible for the things that we're buying and using. Traceability itself does not lead to improved conditions for those workers or the individuals in the supply chains, but it certainly creates a condition in which it's very hard to ignore that these farmers who are in challenging environments have brought you this cup of coffee or chocolate bar. That's one really interesting element of traceability: is it brings a connection in a very disconnected supply chain" (Norton, 2021).

SCT requires SCV as companies aim to evaluate possible risks and gain control over them before becoming transparent. Downstream producer confirms that: "From a critical mineral perspective we haven't been externally transparent, and part of the reason is we have limited visibility. It's difficult to become transparent on something that you yourself don't have good control" [B]. But even if the SCT follows the SCV, it can illuminate things that haven't been discovered during SCV activities. For example, if a specific supply chain is mapped first and some level of SCV is achieved, further implementation of traceability solutions can help identify gaps in the supply chain map. Thus, the company gains access to previously unknown information about supply chains and can investigate data gaps and inconsistencies. This is especially true if traceability technology allows the tracing of minerals on a physical level, as it can highlight where minerals are mixed and how much of the traced mineral actually ends up in the final product [G].

5.2.9. Beyond visibility and transparency

Achieving SCV and SCT is an important step towards achieving more sustainable supply chains, but it is only the first step towards actual problem-solving. The more visibility a company gains over its supply chain, the more issues it will discover [B, F]. But this is also an opportunity to make a significant positive impact in the parts of the world where it is the most needed: "Companies have a major responsibility in effecting change on the ground, especially in places where the state has shown limitations in solving the social and ecological problems" [F].

While SCV and SCT practices highlight areas of improvement, additional investments will be required for supplier development to achieve the desired level of sustainability. When supply chain failures are detected as the result of actions towards visibility and transparency, additional pressure is created on the companies to respond to discovered issues. Companies aim not to suspend relationships with weak-performing suppliers immediately but rather work towards continuous improvement of their performance and mitigation of risks (Philips, 2021; Tesla, 2021). Here partnerships can play a significant role. Collaborative efforts between companies, NGOs, governments, and other stakeholders can pool resources to support supplier development and drive change on the ground.

If specific follow-up actions are taken after the discovery of weak supplier performance, that may eventually lead to more sustainable supply chains. As these actions may require time and resources, focal companies may choose to help their suppliers with improvements. Such measures include:

- Corrective action plans
- Supplier development programs
- Community development programs
- Risk monitoring

Corrective action plans are used to set concrete actions within a reasonable timeframe to resolve the issues in suppliers' performance. Suppliers are responsible for implementing improvements and corrective actions (Apple, 2022b; Volvo Group, 2021). In some cases, suppliers are responsible for the development of corrective action plans (Volvo Group, 2021) or they agree on corrective action plans suggested by a focal company (Volkswagen Group, 2021a). Unwillingness to follow the plan may lead to the termination of the relationship with the supplier (Apple, 2022b).

Supplier development programs include additional resources and assistance provided by the focal company for its suppliers to improve their performance. Such programs may include training on topics like the concept of sustainability and content of the Code of Conduct (Volvo Group, 2021), internal audit skills, health and safety training, responsible recruitment (IKEA, 2022), responsible raw material sourcing (Volkswagen Group, 2021a). In order to approach low-tier suppliers, companies may push tier-1 suppliers to engage their sub-suppliers in such programs (Toyota, 2021a).

Supplier development programs can be customized, like Apple's Subject Matter Expert (SME) program: "Apple experts are sent on-site at supplier facilities to help define customized capability-building plans. Experts connect directly with suppliers to work through improvements and Corrective Action Plans using a variety of capability-building tools. These include one-on-one assistance and online learning through illustrated, self-paced learning manuals that provide instruction and requirements for areas of our Code commonly encountered in daily operations" (Apple, 2022b).

Community development programs aim on improving the quality of life in the areas where suppliers are operating to tackle issues that cannot be solved by suppliers alone. Community development programs can have different forms, for example, responsible mining/safety training for mining cooperatives (ASM), provision of protective equipment, support to increase school attendance, agricultural and financial training for local residents, setting up of small businesses to improve the life quality in the communities (BMW, 2023; Samsung Electronics, n.d.; Tesla, 2021),

To meet the demand for transparency, companies will need to disclose more information about their mineral supply chains, which may also lead to greater scrutiny of their community development programs. This, in turn, can lead to increased stakeholder pressure for companies to expand their community development initiatives and demonstrate their commitment to improving the quality of life in the areas where minerals are extracted. Thus, the pressure for transparency in mineral supply chains can have a ripple effect on a company's broader social responsibility agenda. This pressure is driven by stakeholders who are increasingly seeking to hold companies accountable for the social and environmental impacts of their operations. As a result, companies must be prepared to address these concerns and take proactive steps to demonstrate their commitment to sustainability and ethical practices.

The biggest number of community development programs among studied companies was identified for cobalt mining communities. As was discussed above, cobalt is highly concentrated in one region with long-lasting conflicts and human rights abuses, so this mineral has particular

importance in supporting responsible mining practices and an overall increase in the life quality of local communities. Among such programs are Better Mining and Cobalt for Development.

The Better Mining program was developed by RCS Global, a consultancy firm that specializes in the responsible sourcing of natural resources. The program aims to improve social, environmental, and governance performance in artisanal and small-scale mining (ASM) operations, particularly in the mining of critical minerals in conflict-affected and high-risk areas. At the moment, it covers 55,000 ASM Miners across 3TG, cobalt, and copper mining sites. The program provides a comprehensive approach to ASM due diligence and consists of three main components: assessment, improvement, and assurance. The assessment stage involves identifying risks and impacts associated with ASM operations, including human rights violations, child labor, and environmental damage. The improvement stage focuses on working with ASM stakeholders to develop solutions to these issues, such as improving working conditions, promoting responsible environmental practices, and strengthening governance structures. The assurance stage includes monitoring and reporting on the progress made towards meeting the program's objectives (RCS Global, 2022). The Better Mining program has been adopted by several major companies in the electronics industry, including Apple, HP, and Microsoft. As Apple states in their report: "We work with these programs to help develop their incident review processes and review and monitor incidents generated through their respective reporting systems, including reviewing corrective actions and confirming incidents are closed in accordance with the programs' criteria" (Apple, 2021a).

The Cobalt for Development (C4D) program is an initiative aimed at addressing the issue of child labor and unsafe working conditions in the cobalt mining industry in the Democratic Republic of Congo (DRC). The program was launched in 2018 by the German government's development agency, GIZ, in partnership with various stakeholders in the cobalt supply chain, including companies such as BMW, BASF, Samsung SDI, and Glencore. The C4D includes several key components, including the establishment of pilot projects for responsible cobalt mining, the provision of training and education for miners and their families, the promotion of good governance and legal compliance, and the development of traceability and due diligence systems. The program also involves engagement with local communities and stakeholders to address their needs and concerns, and to ensure that the benefits of responsible mining are shared equitably (Cobalt for Development (C4D), n.d.). Companies may invest in such initiatives even if they are not directly sourcing from the ASM that these initiatives cover: "Although the Volkswagen Group currently does not source cobalt from artisanal mines, it finances the project, along with BASF, BMW Group, Samsung Electronics, and Samsung SDI, with the objective to improve the conditions on the ground and transform the local ASM sector into a safe and socially responsible cobalt source in the long term" (Volkswagen Group, 2021a)

In conclusion, achieving improvements in the sustainability performance of suppliers far upstream from the focal company may not be easy. It requires companies to work closely with suppliers to identify areas for improvement and implement corrective actions, which may involve changes to production processes, supply chain management, and worker training. Also, it may lead to increased complexity of stakeholder relationships and potential power imbalances within supply chains. Despite these challenges, these development programs offer an opportunity for companies to drive positive change in their supply chains and achieve their sustainability targets. However, at the moment, such programs seem to have a rather small scope, and they do not tackle systemic issues.

5.3. SCV and SCT in minerals supply chains as complex adaptive systems

In sections 5.1. and 5.2. SCV and SCT were analyzed from the MTSC theory point of view and mostly focused on the description of practices, their interconnections, and observed challenges. In this section, SCV and SCT in minerals supply chains are explored from the CAS theory point of view that adds another perspective on the importance of SCV and SCT, their challenges, and possible ways to overcome them.

5.3.1. Understanding the nature of supply chains as CAS

CAS has been used by several researchers to describe the complexity of supply chains, and justify that management approach should consider this complexity (Carter et al., 2015; Choi et al., 2001; Touboulic et al., 2018), therefore, it is especially fitting for the context of mineral supply chains because of their complexity. In this study, the CAS model is applied to explain how supply chains develop in order to increase visibility and transparency. In the application of CAS theory, the complex adaptive system itself is the supplier network, including the focal company and all tiers of its suppliers. The theory explores the interaction between a system and the environment – all stakeholders, including customers, legislators, NGOs, governments, etc., or in a broader sense, economic, institutional, and cultural systems (Choi et al., 2001). CAS system explains the dynamics of systems through the prism of three main elements: *internal mechanisms, environment,* and *co-evolution* (Choi et al., 2001).

Internal mechanisms include *agents*, or all members of the supply network: downstream, midstream, and upstream companies, that are "in the process of spontaneous change in such a system", and have "the ability to intervene meaningfully in the course of events", and *schema*: "norms, values, beliefs, and assumptions that are shared among the collective" (Choi et al., 2001, p.353). In the context of minerals supply chains, there are many *agents* that create complex supply networks that can have 5+ tiers of suppliers. An example of a supply chain map for cobalt is introduced below (*Figure 5-8*). The evidence of the constant change in the supply chains and meaningful interventions are found in the literature review (Ebinger & Omondi, 2020; Fraser et al., 2020; Hofstetter & Grimm, 2019; Touboulic et al., 2018), and in several interviews [B,C,D]. *Agents* behave in a way that ensures their best fit into the system, and "dominant *schema* dictates the vast majority of behavior" (Choi et al., 2001, p.353). *Agents* of supply chains can share *schema*, creating collaborations based on shared norms and values (see 5.2.4 collaboration examples). *Schema* can include the intention to build long-term relationships, acceptance of the same sustainability standards, etc. Companies are formulating their *schema* in several ways and then integrating it with supplier policies and other regulating documents. Some of them emphasize the long-term relationships with suppliers (Audi, 2023), aspiration to a sustainable future (Audi, 2023), etc. Companies can give strong signals to their supply chains on sharing the same vision, for example, Audi state that "we collaborate exclusively with partners that share our values".

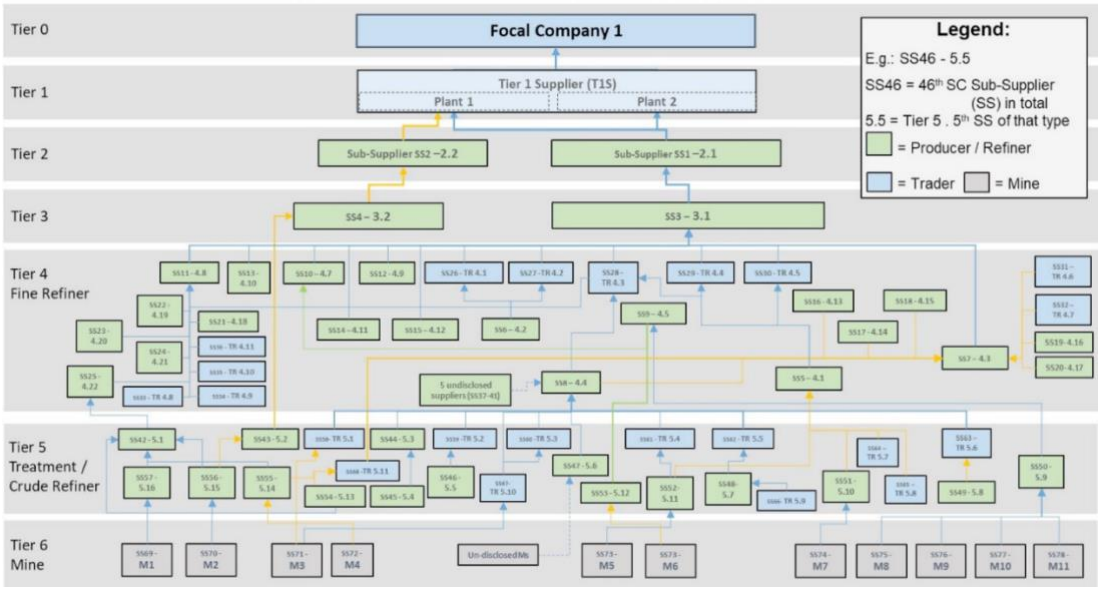

Figure 5-8. Example of supply chain map for cobalt

Source: (Fraser et al., 2020, p.12)

CAS behavior is *emergent* and *self-organized*, or influenced "by the simultaneous and parallel actions of agents within the system" (Choi et al., 2001, p.354). In supply chains, it means that positive and negative practices emerge in different parts of the supply chain, and changes can be led not only by dominant actors (e.g. focal companies), but others as well. These practices can be opposite to the dominant *schema*, thus making the supply chain difficult to control. *Connectivity* and *dimensionality* are also internal mechanisms in CAS theory. *Connectivity* explains that with fewer connections actors can act more independently, while with a high number of connections, agents start to influence each other significantly. *Dimensionality* describes the degree of agents' freedom, where the agents' high autonomy increases the complexity of the system (Choi et al., 2001). In the multi-tier supply chains *connectivity* is very low, as in most cases actors only see their direct suppliers and customers. By increasing the visibility over the supply chain, the *connectivity* will be increasing. This will also have a positive effect on SSCM practices implementation (see section 5.2.7.): more actors will become visible and will be demanded to follow sustainability standards, and thus *dimensionality* and complexity will be decreased.

The environment is the second group of CAS attributes that is external to the given CAS and includes *dynamism* and *rugged landscape*. *Dynamism* means the process of interaction of given CAS and other external systems and elements that results in including or excluding actors from the system, change in their relationships, that leads to the change of the system's prevailing patterns of behavior. Moreover, "the environment can impose new rules and norms (i.e. *schema*), and, as the *schema* is altered, the fitness measure may also change" (Choi et al., 2001, p.355), meaning that actors in CAS constantly have to adapt to the new conditions to preserve their place in the system. In practice, this means that minerals supply chains are highly dynamic, and every moment it is different: "Supply chains are extremely dynamic: they change every hour, every day" [B]. New rules that the external environment poses on minerals supply chains, e.g. new requirements on supply chain due diligence, changes the system and leads to the change of behavior among actors, which can be seen in the progress towards supply chain transparency and elimination of non-compliant agents from it [A, B, E]. The more environmental uncertainty grows, the more need for SCV and SCT increases: "We've gone from a state of somewhat predictable environments to completely unpredictable environments. You're not able to work on the plan anymore, your plan basically is day-to-day, second-to-second reacting to what you

see. So the visibility now is increased because the forecasting no longer is reliable" (SupplyChainBrain, 2022). Environmental uncertainty poses significant challenges to businesses. However, it also presents an opportunity for sustainability professionals to enhance the relevance of SSCM within the company [C].

A rugged landscape means that there are many states that the system in the given environment can attain, so finding the optimal state of the system depends greatly on various individual contributions of the system's actors. The optimal state of the system will greatly depend on the level of technology development (blockchain, AI, etc.), availability of alternative sources of minerals, and many other factors. There is a lot of uncertainty in the environment, and actors of the system are forced to "both exploit existing knowledge and explore new knowledge" to survive. (Choi et al., 2001, p.355). For critical minerals supply chains, significant uncertainty is created by the long-distance supply chains as there are many points where failures can occur, and the location of many *agents* in the highly unstable local context (e.g. conflict-affected and high-risk areas), and all studied companies are in the process of constant search for new knowledge and capabilities to ensure their survivability [A]. Visibility is viewed as one of such capabilities: "When you have the visibility you know these multiple opportunities for failures" (SupplyChainBrain, 2022).

Co-evolution is the last group of elements that include *quasi-equilibrium* and *state change*, *non-linear changes*, and *non-random future*. "CAS both reacts to and creates its environment", and "CAS and its environment interact and create dynamic, emergent realities" (Choi et al., 2001, p.356). This can be seen in several ways in minerals supply chains. An environment consisting of stakeholders and regulations pushes *agents* in the supply network to change their behavior towards more visibility and transparency, and the more visibility and transparency are created, the more advanced regulations are becoming, and the more advanced demands come from stakeholders [A, B]. The more attention stakeholders express to where minerals are sourced and come from, the faster industry will shift [E]. *Quasi-equilibrium* is a balance between order and disorder, that allows the system to maintain some level of order but also react to environmental changes. The further the system is from this balance, the more sensitive it becomes to the changes in the environment and the stronger it reacts to these changes, which can eventually lead to extremely dynamic and system *state change*.

Non-linear changes are the result of the system's complexity: "Large changes in input may lead to small changes in outcome, and small changes in input may lead to large changes in outcome" (Choi et al., 2001, p.356). An example of this can be the implementation of conflict minerals regulation in the USA with a goal to increase supply chain transparency and ensure that human rights are respected in minerals sourcing, but it led to the big brands' complete ban on sourcing from conflict region, and further increased poverty and human rights violations (Global Witness, 2017; Hanai, 2021). And the opposite can also take place: one small change in the system can lead to changes in many other system elements. For example, SCT can lead to greater benefits on sustainability: procurement from local suppliers, reduction of emissions, etc., affecting local communities and the economy as a whole [A].

Non-random future is a characteristic of CAS that shows that although "it is true that small changes may lead to drastically different future paths; however, the same characteristic pattern of behavior emerges despite the change". As industry actors mention, SCV and SCT represent the fundamental change of the system: "We come from totally different ways of working and we want people to change behavior, ways of thinking. We want to become circular in the way we do business. That's a massive change process" (RCS Global, 2023). But at the same time, small changes are already happening and industry actors notice the transformation to more responsible sourcing of minerals: "You begin by digitizing suppliers and supply chain

information, then through a process of digitalization of your systems and processes you can start to evolve in the way that you are able to work more effectively to have data-driven approaches to prioritization and risk management and eventually this leads to a process of transformation in terms of the whole way that the organization is able to conduct responsible sourcing" (RCS Global, 2022).

Challenges of SCV and SCT from a CAS perspective

From all the information gathered for this study, it can be clear that the dominant schema now is limited visibility. Agents at all levels of the supply chain have strong motivations to resist changes. Downstream companies may resist changes as they do not have enough resources and power to solve the deep-rooted problems in the supply chains that their stakeholders will be expecting from them. Moving slowly and cautiously and solving one issue at a time seems the prevailing approach in the downstream segment. Midstream actors experience both low pressures from the environment and high internal motivation to keep undisclosed commercially sensible information to survive on the market. Upstream actors (except for the large mines) do not have enough resources or capabilities to change the way they are doing business tightly connected with wider economic and political problems on the state level. They rely on the possibility of entering the supply chains in the situation of low SCV. If they will move from the invisible part of the supply chain to the visible, they most likely are excluded and lose the opportunity to make money for a living. The combination of these factors makes the SCV undesirable for many actors in supply chains.

The key question after analyzing the supply chains through CAS is how the situation can be actually changed. The regulatory pressure seems to push companies to have more attention to the SSCM: "As the regulation is changing and is making it mandatory for suppliers to open up about the supply chain, I think we will get, over time, full supply chain transparency, if not for the entire supply chain, at least for groups of components that are very critical. I think it's going to change a lot and it's going to make our work a lot easier" [D]. But when the pressure is coming from the environment but not the internal understanding of the benefits and goals of transformations, companies may only aim at achieving the minimum requirements of regulations but not push systemic changes [F, G]. As an industry expert highlights "What goals do companies want to achieve by implementing traceability? If it is not just compliance with regulations, then what other goal can it be?" [G]. A shared goal (*schema)* is the key element that enables changes in CAS, and this goal should be clear and shared by all actors [G].

The heterogeneous nature of environmental pressure also determines the different progress of SCV and SCT in different minerals supply chains and different levels of motivation among actors at different levels of supply chains. As long as the stakeholders create the most pressure on conflict minerals and cobalt, companies will be more motivated to put their resources in these specific supply chains, and negative sustainability issues will continue to arise in other minerals' supply chains. But in the future, experience gained in implementing solutions for priority supply chains can be more easily scaled to other supply chains: "Because it's very expensive and requires a lot of resources, it seems to me that at least in the near term it's going to be a niche solution for some critical products, whether it's metal or non-metal. So it has to be something going on with a product, that affects reputation or brings other risks, so that there would be such a powerful incentive, to pay a lot of money to make it happen. If the solution scales and become less expensive for someone to jump in, then it's quite possible that some other not-so-critical players will show up there" [A].

Industry experts also highlight, that before SCT will be commonly accepted practice, the liability issue should be solved. As most of the supply chains are now shared between many downstream

companies, there should be a "shared commitment for improvement" in any form [G]. It is highly unlikely that a single company will be able to solve the issues identified in the supply chains, and the existing initiatives (see section 5.2.9) are relatively small and local. Massive collaboration work is required not only for establishing SCV and SCT but in creating new approaches and commitments for solving the systematic issues in supply chains.

One of the most important issues seems to be the public attention to how the end product is created and where are all the materials are coming from. Due to low visibility, for the end customer, it is easy not to look at these issues and not ask these questions. But as SCV and SCT increase, it triggers more attention to supply chain issues. And the next question will be if the customer is ready to pay extra for a product that has proven to have responsible sourcing practices for the minerals that it contains [E]. In the end, there should be a business case for a company in investing in SCV and SCT, and in "shared commitment for improvement" in supply chains, and this means that the market should be able to offer enough compensation for the additional value created [G].

5.3.2. Changing the system's behavior

To gain insights from CAS theory, the following section explores the implementation of the Battery passport case through a CAS lens (see more on Digital product passports as SCT tool in 5.2.6). First, a brief introduction to the case is given. Second, the main elements of CAS are explored based on the case published materials, interviews, and own observations. Third, the main lessons learned are formulated that can also have value for the development of any other SCV and SCT tools.

Introduction to the Battery passport case

The Battery Passport is a specific example of a digital product passport described in 5.2.6 and represents a digital record that provides information about a battery's composition, materials' origin, a chain of custody, and various sustainability indicators. This information can help facilitate the recycling and repurposing of batteries, monitoring risks related to human rights, and reducing waste and negative environmental impact. The *environmental* pressure in the battery industry has increased significantly in the last several years as a result of *co-evolution* processes with other sectors towards decarbonization and achieving net-zero goals: batteries are an essential part of electric vehicles (EVs), that play a crucial role in decarbonizing the transportation sector. At the same time, the production of batteries relies heavily on metals such as cobalt, nickel, and lithium, which pose a bottleneck to the development of the EV industry: these metals are mainly sourced from regions with inadequate legislation and low sustainability standards, and an increase in demand for them could have adverse effects on the environment and human rights in these areas (Burton, 2022; Castelvecchi, 2021). There is growing legislation pressure on the battery industry: the new Battery Regulation will demand battery passports with sustainability and material provenance data for all EV batteries placed in the EU market (Proposal No 2019/1020, 2020).

Global Battery Alliance (GBA) is a stakeholder initiative that aims on creating a platform for stakeholder dialog to develop commonly accepted standards on traceability of battery minerals (ynonno cobalt, nickel, lithium, magnesium), enhancing circularity, measurement of sustainability indicators (GBA, 2023). In 2022-2023 the GBA implemented three pilot projects of Battery passports with the participation of two different downstream companies, three midstream producers (battery), and three blockchain-based traceability technology providers. The process involved forming a working group consisting of companies representing the entire "cradle-to-gate" value chain from upstream (mine) to downstream (automotive) producers, as well as traceability technology partners. The Battery Passport initiative involved testing the different

digital platforms for their ability to track minerals on the entire lifecycle of a battery, creating SCV and SCT in the battery supply chain. The GBA developed and published rulebooks for the GHG emissions calculations, the child labor and human rights indices. These rules were integrated into data collection templates and guidelines for individual company reporting. The unified standards of sustainability indicators reporting allowed individual data from different sites to be aggregated into a product-level battery passport, considering actual material flows. In addition to sustainability data, materials provenance data and technical data were collected. The working group identified critical issues and collected insights to ensure continuous improvement in future processes.

Battery passport through CAS perspective

The GBA battery passport initiative is a collaboration of *agents* – all members of battery minerals supply chains that are working on the new industry *schema* – a set of sustainability and material provenance standards that will change how the industry is operating. This collaboration is a *self-organized* united initiative that *emerged* in the different parts of the supply chains as a result of different *environmental* pressures: downstream producers (actors in the automotive industry that falls under battery regulation) and upstream producers (the consortium of mining companies that want to secure their markets in the situation of growing public concerns over mining practices). Starting from those *agents* that share the same *schema,* they started to push those who were more resistant to transparency. By creating collaboration these actors have more power to involve in the initiative than other actors in the supply chain like battery producers that are experiencing less pressure from the *environment*.

Shared *schema* is a key condition for the battery passport implementation, as it helps to create trust and share the information: "Although there's a technological element to this work, some of this is simply about having good relationships and trust between entities because you're providing a lot of data. People got a lot more comfortable with sharing information due to the fact that we're participating in this together with the same objective" (RCS Global, 2023). GBA provides a communication platform for companies to promote their interests while creating trust through dialogue and building a common position [E]. "GBA allows companies to form a common language in terms of ESG targets and indicators, to form common standards, which will take into account the opinion of all actors and will be accepted by all market participants. The fact that GBA is a multi-stakeholder organization makes it possible to integrate the vision of different parties and ensure that decisions are made" [E].

All agents have their own problems that they want to solve by entering collaborations like GBA. There are a lot of incentives for organizations to come together, for example, lack of understanding of where to start in solving a problem, lack of industry experience (for technology providers), or lack of technological competence (for industry actors) [G]. "By creating the testing ground, providing the clear uniform conditions and general rules of the game the new technologies are tested, all participants can see how technologies work in practice. In general, now there are agreements about the rules of the game, a market is being created where there are several competitive solutions, and there are agreements about access to data" [E]. As was discussed above, CAS cannot be controlled by the focal company even if it is a dominant actor due to its complexity and dynamism. At the same time, a collaboration of actors that share the same *schema* creates the necessary dominance to influence the systems' behavior. The formation of the GBA by companies, including not only focal companies but also midstream and upstream ones, is a clear indication that they did not possess sufficient power individually to address the issue of sustainable mineral sourcing in their supply chains [G]. The need for a collaborative effort highlights the complexity of the challenge and the recognition that a collective approach is required to achieve the desired outcomes.

A collaboration between agents from the different levels of the system (upstream, midstream, and downstream) and the external environment (technology and services providers) allows to increase system's *connectivity*. The GBA ensured overall governance, proper communication, and coordination among the pilot projects, ensuring that the same standards of outputs were maintained across all projects to ensure consistency and comparability. This allowed to significantly decrease the *dimensionality* of *agents* in the system, thus reducing its complexity. Additionally, the battery passport represents a *co-evolution* process where different agents are collaborating to achieve it under increasing pressure of the external environment [A, B, E]. It follows "an ecosystem approach connecting and engaging businesses, IT solution providers, regulators, auditors, public, international and non-governmental organizations" (GBA, 2023). As industry players state, "IT solutions are needed to get all requirements and regulations under one roof" (RCS Global Group, 2022). This is also supported by upstream producer's testimonials: "Mining companies see how difficult it is to collect data for clients and, ideally, they need to automate it, because they're getting these requests, they're processing them, and they can't answer everything fast enough" [A].

However, as was mentioned in section 5.2.8, the current state of the supply chains does not allow visibility and transparency. Before it can really be achieved, the system may also find other states that can be optimal to the existing pressure and internal barriers of the system, representing *a rugged landscape* in the CAS theory. As one of the battery passport participant states, "We need to get that balance between what the regulation is trying to achieve and what is practical. Some of the regulation's steps don't understand the realities of supply chains: there are issues around confidentiality, data governance, etc." (RCS Global, 2023). Achieving SCV and SCT seems to be not a linear process, but a motion from one state of equilibrium to another, gaining more knowledge and capabilities at every step of the way.

There is not enough evidence yet to make conclusions on *co-evolution* processes, but it is clear that more and more companies start to join the project, involve in the discussion of challenges, and work towards finding commonly accepted solutions (GBA, 2023). The more agents are joining the initiative, the more chances that developed solutions will be implemented by the majority of the industry, thus it will drive the system from the current state of *quasi-equilibrium* to the new state where SCV and SCT are accepted and implemented by the industry: "the new norm is created" [G]. Based on the collected testimonials it can be assumed that SCV and SCT will lead to massive changes in the minerals supply chains, and at the same time, this characteristic of *non-linear changes* makes SCV and SCT extremely difficult to implement as some environments may not be ready for the following economic and political changes.

There are several **lessons learned** from the battery passport case that can be used in the development of any other SCV and SCT tools:

- To make scalable and lasting changes, it is crucial to consider the interests of all stakeholders involved in the supply chain. By understanding and incorporating their perspectives, sustainable initiatives can be developed with broader support and long-term impact. It can be possible because the created *schema* will be acceptable by *agents* and thus become dominant (GBA, 2023).
- Everyone should understand and share a common goal [G].
- Open collaboration plays a significant role in addressing key issues related to standards, processes, and interoperability. By fostering collaborative partnerships and actively working through these challenges, stakeholders can collectively develop frameworks and solutions that enhance supply chain visibility and sustainability (increased *connectivity* and decreased *dimensionality*) (RCS Global, 2023).

- Building trust is a critical factor in successful supply chain management. While technology is important, establishing good relationships and trust among entities is equally essential, especially when dealing with sensitive data. Trials and demonstrations can create an atmosphere of trust, enabling participants to discover common ground and strengthen relationships with stakeholders (increased *connectivity*) (RCS Global, 2023).
- Another important thing is who are the agents of change. Implementing changes, adopting new practices, and creating collaborations are done not by the organization itself, but by concrete people in charge of this. Thus, one of the most important aspects is people that are actually driving changes forward. Practitioners highlight that it is important that people involved are having entrepreneurial mindsets, have an understanding of the big picture, and can create trust with partners [G].
- One of the success factors in achieving effective supply chain visibility is getting a large number of companies on board by meeting their specific requirements. This entails keeping up with updates on standards and industry trends to ensure readiness and responsiveness to new regulations and other requirements [A].
- Adapting to the early stage of market development with a lot of issues still to be solved: "all the traceability projects are mostly start-ups, and they have all the risks and challenges of start-ups like high initial investments, possible failures in business model or lack of skilled staff. Also, it is challenging to get the full supply chain on board, especially midstream. Also, they need to solve the challenge of disclosing one set of data but at the same time not disclosing the sensitive data. If you have something missed somewhere, that's a very big reputational risk" [A]
- Starting somewhere is key to initiating supply chain visibility efforts. By identifying and engaging with stakeholders who share a similar interest in visibility, it becomes easier to target low-hanging fruits and demonstrate the benefits of increased transparency (shared schema) (Mines, 2021).
- Tools used for supply chain visibility need to be highly flexible to accommodate the diverse industries, countries, and continents involved. Adaptability and ease of implementation are essential in navigating the complexities of supply chains and ensuring effective data management (Mines, 2021).
- Ultimately, the battery passport serves as a transparency tool to identify, highlight, and, where possible, quantify issues across the battery value chain. While it may not eliminate root causes entirely, its purpose is to encourage and enable stakeholders within the battery industry to drive improvements and promote greater sustainability (GBA, 2023). By identifying areas that require more attention and implementing targeted audits, organizations can gradually build trust, and transparency, and improve performance throughout the entire supply chain (RCS Global, 2023).

In conclusion, there is significant progress in achieving SCT and SCV made. The more changes are happening, the more pressure is created by the *environment,* and the more system will be moving to the new state, where SCV and SCT will be easier to implement. The key challenge in this way seems to be a collaboration between a big number of actors inside the supply chain and around it, and thus the first step for the companies can be involved in collaborative initiatives around their supply chains.

6. Discussion

The aim of this chapter is to critically review the findings of the thesis and provide a foundation for the conclusion. Firstly, the results are analyzed in the context of the research questions and aims of the thesis, and their significance and relevance are discussed. Secondly, the research methods will be evaluated for their appropriateness in terms of design and implementation. Finally, the contributions and limitations of the findings are discussed explicitly, and suggestions for further research and application are provided.

The objective of this thesis research is to examine the process of increasing the sustainability performance of multi-tier supply chains of large multinational companies. Transparency and visibility of supply chains are the core conditions that allow to implement sustainability standards along the supply chain as overwise companies cannot influence actors that they do not know about. At the same time, the importance of SCV and SCT is increasing significantly for companies, as they aim to remain competitive and meet stakeholder demands. Without SCV, companies are only aware of their direct suppliers and are unable to effectively manage risks and impacts that may arise within their complete supply chains. On the other hand, SCT allows companies to assure stakeholders of high sustainability standards and responsible sourcing practices for materials used in their products. Despite its benefits, achieving SCV and SCT can be challenging due to the systemic issues present within supply chains.

Specifically, the study focuses on minerals supply chains, which are known for numerous violations of human rights and significant negative environmental impacts. As minerals are vital components of electronics products, achieving sustainability goals across the supply chain is a high priority for many downstream companies. The research investigates the factors that drive or hinder the implementation of supply chain visibility and transparency, as well as the necessary conditions for their successful implementation. Additionally, the study evaluates the benefits and limitations of supply chain visibility and transparency for sustainable supply chain management. The findings of this research provide essential knowledge for the broader adoption of sustainable supply chain practices in large multinational companies with complex multi-tier supply chains. This thesis addresses the following research questions:

RQ1: what role do SC visibility and transparency play in the SSCM process

RQ2: what approaches do large multi-national companies implement to achieve SC visibility and SC transparency and what different factors influence a company's choice of approaches to SCV and SCT

RQ3: what are key challenges and success factors in the process of establishing SCV and SCT

In this discussion chapter, I compare and contrast my findings with both academic literature and practical cases to put findings into context and provide a comprehensive overview of the current state of research and practice in SCT and SCV. I also discuss the strengths and limitations of the theoretical frameworks applied in the thesis study, multi-tier supply chain theory (MTSC) and complex adaptive systems (CAS), and how they can help to understand and address the challenges of implementing SCT and SCV in practice.

6.1. Discussion on main findings and conclusions

SCT and SCV have been the focus of growing attention in academic literature, as they are increasingly seen as essential components of SSCM. However, the literature has not yet explored all the challenges associated with implementing SCT and SCV in-depth. Moreover, new practical

cases are emerging that provide new information about the application of SCV and SCT tools and technologies in practice. This can enrich current academic research and contribute to a better understanding of the benefits, limitations, and challenges of implementing these practices.

The present study employs two theoretical frameworks to analyze the process of achieving sustainability goals in multi-tier supply chains: **multi-tier supply chain (MTSC) theory** (Gong et al., 2021; Tachizawa & Wong, 2014) and **complex adaptive systems (CAS) theory** (Carter et al., 2015; Choi et al., 2001). MTSC theory provides a simple and straightforward framework for understanding the main factors and approaches to sustainable supply chain management. It emphasizes the importance of collaboration among actors in different tiers of the supply chain and the integration of sustainability factors into supply chain strategy decisions. Despite its strengths, MTSC theory has limitations, particularly in capturing the complexity, dynamics, and non-linear behavior of multi-tier supply chains. In contrast, CAS theory recognizes supply chains as complex adaptive systems that exhibit emergent behavior, self-organization, and adaptation to changing environments. This approach enables a deeper understanding of the behavior of supply chains and how sustainability interventions can influence their dynamics.

Supply chains have long been recognized as complex systems, characterized by a high degree of interconnectivity and interdependence among their components. However, more recent research has highlighted the fact that **supply chains can also be considered complex adaptive systems**, which are capable of responding to external stimuli and changing conditions in a dynamic and often unpredictable manner (Choi et al., 2001). One key feature of supply chains as complex adaptive systems is their ability to self-organize and adapt to changing circumstances which is critical for ensuring the resilience and sustainability of supply chains in the face of ever-changing market conditions and environmental pressures (Carter et al., 2015). At the same time, however, the adaptive nature of supply chains also means that they can be difficult to predict or control, e.g. even for focal firms. For instance, disruptions in one node of the supply chain can trigger complex ripple effects throughout a supply chain, with impacts that may not be immediately apparent. Additionally, supply chain decisions made at one level or node of the network can have unintended consequences for other nodes or levels, further complicating efforts to manage supply chain performance. A great example of this could be seen during the COVID pandemic (Castka & Searcy, 2023). Stakeholders possess the ability to exert influence on the supply chain by "creating" new issues or by applying pressure on emerging ones. From a CAS perspective, the focal firm cannot exercise complete control over all aspects of the supply chain (Touboulic et al., 2018).

RQ1: what role do SC visibility and transparency play in the SSCM process

SCV and SCT can trigger significant changes in the complex supply chain systems and lead to a new state of this system, making it more optimized, efficient, sustainable, and responsible, as also confirmed in other academic research (Castka & Searcy, 2023; Heldt & Beske-Janssen, 2023). SCV can help better identify the performance of actors and the connections between them and provide information to make better and more flexible decisions. The same effect is identified for the application of satellite technologies for SSCM by Heldt & Beske-Janssen (Heldt & Beske-Janssen, 2023). SCT, on the other hand, can promote trust and collaboration among stakeholders, leading to better coordination and communication within the system. By improving SCV and SCT, companies can better understand the dynamics and interactions within their supply chains, which can help them respond more effectively to changes and disruptions. For example, by having visibility into their suppliers' operations and potential risks, companies can proactively address any issues and minimize their impact on the business. Additionally, by promoting sustainability practices throughout the supply chain, companies can create a more resilient and responsible system and efficiently manage

sustainability-related risks. This goes in line with academic literature, as some authors also mention this positive connection between concepts, for example, Tachizawa & Wong conclude that "transparency (i.e. product visibility and end-user knowledge of the supply chain) has a positive effect on the adoption of social sustainability by suppliers" (Tachizawa & Wong, 2014).

The research findings confirm that **SCV is a core condition for SSCM and SCT,** as discussed in academic literature (Ebinger & Omondi, 2020; Fraser et al., 2020; Montecchi et al., 2021). Without visibility, it is difficult for companies to identify and manage the risks and impacts of their entire supply chains. However, SCV alone is not sufficient to ensure sustainable supply chains. Rather, it requires additional investments in supplier development to achieve the desired level of sustainability. Also, partnerships between companies and their suppliers can play a critical role in driving sustainable practices throughout the supply chain. Once the hotspots are identified through improved visibility, companies can take action to improve sustainability conditions on the ground. This requires going beyond mere data collection to engaging with suppliers and making targeted investments in their operations.

Improved SCV is a necessary step before making supply chain information available to stakeholders through SCT. In order to achieve transparency in their supply chains, companies must first establish a sufficient level of visibility themselves and implement practices to demonstrate to stakeholders that risks and impacts are effectively managed. While transparency alone may not lead to sustainable supply chains, it can provide higher-quality information on supply chain risks than visibility alone. This study also highlights that improved SCT can lead to increased SCV as companies gain access to previously unknown information about supply chains and can investigate data gaps and inconsistencies. This in turn can help identify blind spots in the supply chain and provide more informed sustainability risk management and help companies develop more effective mitigation strategies.

RQ2: what approaches do large multi-national companies implement to achieve SC visibility and SC transparency and what different factors influence a company's choice of approaches to SCV and SCT

Current practices do not allow for achieving full supply chain visibility. First, the review of the sustainability reports of the companies in the scope of this study shows that companies establish responsible sourcing programs only covering high-priority suppliers in high-priority mineral supply chains and managing risks to a certain extent. For example, most used tools like supplier questionnaires only provide self-reported information, and more in-depth audits are conducted mostly towards a limited number (5-15%) of tier-1 suppliers. Also, tools for identification and assurance of lower-tier suppliers like the Responsible Minerals Initiative (RMI) assurance program and data collection templates do not cover the upstream producers and all the indicators required by regulations and stakeholders.

Second, the success of existing tools for SCV relies heavily on the willingness of suppliers to transmit requirements further down the supply chain and ensure compliance with them by their suppliers and sub-suppliers. The task of obtaining supply chain information from midstream suppliers is particularly challenging as they may have little incentive to share such information as it contains commercially sensitive data. However, if the buyer holds significant power in the supply chain or if there are legal obligations for suppliers to disclose supply chain information, this cascading strategy can work. In rare cases, if a focal company has sufficient power and resources it can establish direct sourcing of raw materials. Thus it can have direct contractual relationships with suppliers beyond tier-1 that allow it to require compliance with sustainability standards from the upstream suppliers.

Third, current approaches only provide a snapshot of the supply chain state at one moment in the past and are not able to capture the supply chain dynamics and complexity. This limitation of current practices is extensively discussed in academic literature (Ebinger & Omondi, 2020; Touboulic et al., 2018). This study confirms and expands on supply chain complexity and dynamics as key considerations in establishing SCV/SCT. SCV and SCT are extremely difficult to achieve because of an enormous number of suppliers involved (hundreds of thousands), the diversity of products and materials, several points where raw materials are processed and mixed, the geographic dispersion of supply chain partners, and the different character of regulatory and compliance requirements in different countries, continuous changes and fluctuations that occur within a supply chain.

In the context of responsible mineral sourcing, there is no universally applicable approach due to the diverse regulatory contexts, stakeholder pressures, and complexities inherent in different mineral supply chains. Additionally, the availability of external tools (such as supplier databases and assurance schemes) and potential partners varies across these supply chains. Consequently, despite the increasing significance of supply chain visibility and transparency in this domain, companies encounter substantial difficulties in assessing and disclosing their supply chain practices. Many companies have limited visibility beyond the smelter/refiner level, and there are only a handful of companies that claim full visibility over priority supply chains such as 3TG and cobalt. While 3TG and cobalt remain the priority supply chains for most companies, some have begun reporting on responsible sourcing practices for other minerals such as lithium, nickel, and mica.

Also, because the SCV and SCT in minerals supply chains are still low, there is too early to say if some benefits that are mentioned in academic literature exist in practice, for example, price advantage and increased purchasing power (Ernst & Young, 2022; Kalaiarasan et al., 2022), green consumption (Bai & Sarkis, 2020), etc. Currently, companies primarily see benefits in enhanced control over supply chain risks and preparedness for forthcoming regulations.

New technologies such as blockchain, AI, and digital twins have the potential to move SCV and SCT to a new level, allowing to collect data from a large number of suppliers and transmit it through all tiers of a supply chain in a reliable way. This includes data on the origin, chain of custody, and sustainability indicators that can be seen in real-time. However, it relies heavily on the willingness of supply chain actors to cooperate, create trust, and change existing practices. Moreover, it is still necessary to have an established assurance process for supply chain actors before this data is collected using digital technologies and invest in the development of suppliers which are not compliant with the focal company's sustainability standards.

In recent years, the implementation of real-time traceability programs has gained attention among organizations due to the emergence of new regulations and increased reputational risks associated with non-compliance. This is also reflected in the academic literature where challenges and opportunities of emergent technologies are explored, for example, Bai & Sarkis explores the decision-making process when introducing blockchain for SCT, Ebinger & Omondi explore the digitalization process in SSCM, and Gligor et al. provide a case study of implementation of blockchain for SCT (Bai & Sarkis, 2020; Ebinger & Omondi, 2020; Gligor et al., 2022). Several projects have been initiated to develop blockchain-based traceability programs for minerals such as gold, cobalt, and lithium. These initiatives have been primarily focused on pilot testing, and only a few have transitioned to full-scale implementation. However, successful pilots have shown the potential benefits of real-time traceability programs in improving supply chain visibility and transparency, enhancing risk management, and promoting responsible sourcing practices (Circularise, 2023; *Minespider*, n.d.; RCS Global, 2023; ReSource, 2023). The growing interest in these programs indicates the need for continued

exploration and research on their effectiveness in addressing the challenges of supply chain sustainability and key success factors that can make these programs scalable and applicable to multi minerals supply chains.

Several important factors influence the choice of approaches to SCV and SCT. First, it depends significantly on the regulations in force or expected to come shortly. This factor is not represented significantly in the reviewed literature and interviewed companies both welcome the regulation and express concerns about its practical implementation. A situation is now being created where regulation requires companies to have far more SCV and SCT than the existing solutions and technologies on the market can provide. On the other hand, this is a significant incentive to invest in new technologies and accelerate their development. Second, high stakeholder pressure for SCT creates stimuli to develop it and thus develop SCV, but with the proper level of caution so as not to cause more reputational risks and negativity from the stakeholders than in the absence of supply chain information. Third, various factors associated with each mineral's supply chain, such as criticality, level of dependence, and power dynamics, influence the prioritization of implementing SCV and SCT practices. Given the absence of readily available tools and technologies in the market, companies are required to experiment with solutions, navigate challenges, and gauge the responses of supply chain actors. Based on these factors, companies must make informed decisions on where to initiate changes toward achieving SCV and SCT. These factors are well-described in the MTSC theory (Tachizawa & Wong, 2014) and most of which can be applied to the minerals supply chains.

RQ3: what are key challenges and success factors in the process of establishing SCV and SCT

In line with findings from the literature review, there is a large amount of evidence that companies struggle to involve their sub-suppliers in any SSCM practices, including SCV and SCT. In the absence of direct contractual relationships and control over sub-suppliers, companies often rely on their direct suppliers to promote SSCM practices further up the supply chain. Focal companies are thus dependent on the willingness of their direct suppliers to cooperate with and support their efforts to promote sustainability (Grimm et al., 2014, 2018). At the same time, the examined case showed that if there are enough actors in the different parts of supply chains that see value in SCV and SCT they can create pressure for the resistant supply chain actors and make them accept new practices.

The thesis research validates the notion expressed in the academic literature that the shift towards more sustainable practices within supply chains cannot be mandated from the top or fully controlled, as supply chains are in a state of constant flux and are influenced by a dynamic environment (Touboulic et al., 2018). This means that many changes in supply chains occur regardless of the will of the focal company and rely more on collaborative processes and mechanisms to compensate for pressures arising in the environment. The increasing pressure from regulators and stakeholders will drive supply chain actors to be more receptive to SCV and SCT practices. As end consumers raise questions about the origins of materials, this heightened attention will further catalyze changes within supply chains.

This study further expands on the challenge of focal companies' resistance to SCV and SCT, formulated in several academic articles (Garcia-Torres et al., 2022; Sodhi & Tang, 2019). The push for transparency in supply chains has created a paradoxical situation for companies: while stakeholders demand greater transparency and disclosure, companies that do become transparent often face increased scrutiny and pressure (Meinlschmidt et al., 2018). NGOs and stakeholders may use transparency to bring attention to supply chain issues and pressure companies to take action (Hartmann & Moeller, 2014). However, this leads to a cycle of

escalating demands for disclosure and action, putting more pressure on companies. The same dynamic applies to SCV. Once a company achieves visibility, stakeholders hold it accountable for any unethical practices throughout the supply chain, expecting transparency. However, this thesis suggests that the pressure from stakeholders may cause targeted companies to resist SCV and SCT if it is not ready yet to accept the possible consequences. To achieve SCV and SCT and navigate the associated challenges, additional resources must be invested to help suppliers improve their sustainability performance. It is difficult to determine the exact amount of resources required until SCV is achieved and an improvement strategy is developed.

This research also highlights more systematic challenges than are identified in academic literature. To a large extent, SCV and SCT are difficult to achieve due to the systematic problems within supply chains, which require re-inventing supply chains. This process will require extensive collaboration among various actors within supply chains who share common goals and values, as no single focal company can lead these changes in isolation. The data emphasize that the issue lies at the core of supply chains: supply chains as they work now are not designed for visibility. The competitiveness of many actors depends on the information disbalance by protecting commercial information about suppliers, sources of products, and specific characteristics of the deals. Some experts assume that SCV and SCT are a threat to the current rules of supply chain operations. Some actors may lose their competitiveness if additional supply chain information is disclosed, and some can even be removed from supply chains when visibility leads to supply chain optimization. This leads to the high resistance towards SCV and SCT in supply chains that require additional efforts to be overcome. At the same time, raised demands for verification of supply chain sustainability data may lead to the growth of the service market, including auditors, verifiers, technology providers, and others. Furthermore, there are different levels of technological development in the upstream and downstream, and new standards will require massive digitalization requiring the least developed actors to increase their technological capabilities significantly.

The findings suggest that no single organization knows how to achieve SCV and SCT alone, as it requires extensive cooperation, a high level of trust, and a strong will from all SC actors. At the same time, anti-trust legislation prevents cooperation, and there are many things to agree upon, such as how the SCV/SCT service market will operate and which standards should be used by all actors. Furthermore, there is a different level of technological development in the upstream and downstream, and new requirements will demand massive digitalization making least developed actors increase their technological capabilities significantly. In terms of focal companies, the implementation of new technologies and re-invention of approaches to supply chain management can pose significant challenges for companies. Big corporations may be slow in implementing these changes and look for the "perfect solution" that are not yet on the market. Implementation of SCV/SCT requires companies' agility, and readiness to innovate, try new solutions, fail, and learn from failures.

Resource requirements pose another significant challenge. Even though the findings of the study confirm that companies see SCV as a key condition for better sustainability risk management in supply chains, there is a lack of business cases in minerals supply chains that can outline the advantages of SCT. Addressing supply chain issues, enhancing technological capabilities, and processing vast amounts of information demand substantial additional resources. It is still unclear how these costs will be shared, or will it lay as an additional burden to a focal company as the one who face the most pressure from stakeholders, or numerous small and medium-sized businesses in the supply chain that may not have the necessary resources and capabilities. Overall, there is insufficient evidence to support the notion that SCT leads to improved supply chain governance and greater accountability of supply chain actors. In the end,

companies will discover many unknown risks in supply chains and will have to deal with them, through responsibility, investment, resources, and more pressure from stakeholders.

The prevailing approach to SSCM has been based on the belief that suppliers and sustainability concerns can be fully known and controlled. Some researchers also highlight that current studies oversimplify the operationalization of transparency in the supply chain context (Fraser et al., 2020). However, this thesis reveals that viewing mineral supply chains as complex adaptive systems provides a deeper understanding of the origins of emerging issues and dynamics, and offers strategies for addressing them, even in situations where these dynamics cannot be predicted in advance. The current supply chain system is not in the optimal stage and does not respond adequately to environmental pressures, making changes unavoidable. Supply chains both react to environmental pressures and create them, so more visibility can lead to higher pressure for visibility and transparency. SCV is a small change, but it will lead to bigger system changes, resulting in completely new supply chains that are more efficient and sustainable. Visibility is not the end state of the system, but a process of many steps and actions. Companies can already prepare for the coming changes and create benefits.

This study confirms the position that SCV and SCT are not achievable in current reality (Garcia-Torres et al., 2019). However, supply chains are already changing, and many factors will continue to drive the system to the new state, where SCV and SCT are necessary characteristics of the supply chain. Some authors highlight that at some point SCV and SCT will become a norm for supply chains (Fraser et al., 2020), and trends identified in this research confirm that. There are actors on all levels of supply chains that share the same vision of supply chain visibility and sustainability and are interested in getting more market share by eliminating actors with low practices. Those who are not following the systems' new practices may be excluded. Pressure from the environment will continue to increase, from regulators and other stakeholders, from GHG emissions reductions, and human rights protection in the supply chains to other sustainability indicators.

6.2. Methods and limitations

This study employs a qualitative research design incorporating elements of ethnography and case study methodologies. The primary sources of data for the study consist of 47 published documents from 16 companies operating in the automotive, electronics, consumer goods, and industrial goods industries. Additionally, 5 webinars and 10 reports from industry associations and consultancies were utilized. The perspectives of practitioners were gathered through 7 interviews. To organize the collected data from multiple sources, a coding system was developed based on the literature review and theoretical frameworks.

One of the main strengths of the qualitative approach used in this study is that it allowed the authors to gain a multi-stakeholder perspective, which included downstream, midstream, and upstream companies, technology providers, and industry associations. Research studies predominantly focus on the focal firm and its direct suppliers, neglecting the perspectives and practices of midstream or upstream actors. Limited access to these actors hinders understanding their roles and contributions within the supply chain. Consequently, a gap exists in knowledge regarding up/midstream actors, emphasizing the need for inclusive research that encompasses the entire supply chain. The chosen approach enabled to identify major challenges and gain a good understanding of how minerals supply chains are functioning. Furthermore, the case example provided valuable insights on the development of SCV and SCT in minerals supply chains, illustrating how these practices are evolving with the implementation of digital technologies.

However, the current study has some limitations. Firstly, as the number of interviews conducted is limited, the study can only highlight one piece of the complex puzzle of supply chains. This means that other challenges and success factors that are important in the context of minerals supply chains may not have been captured. Additionally, the study does not provide a holistic picture but rather a snapshot of the companies in scope. These factors may limit the generalizability of the findings. Simultaneously, interviews inherently carry a subjective element. To enhance reliability, data triangulation was employed, incorporating multiple sources such as documents, webinars, observations, and participation. This approach served to corroborate interview findings from different perspectives and provide a more balanced and neutral view of the information.

Another limitation of the study is that it was based on the assumption that companies in minerals supply chains have at least some state of SCV and SCT that can be analyzed. However, in practice, there was very little information in the companies' reports and websites, and those publications provided the bare minimum of information. This contradicts the results of the studies on the implementation of digital technologies for SSCM, for example, Ernst & Young, 2022, showed that most companies have such projects in place. This may be due to the fact that companies are not yet ready to respond to increased stakeholder pressure for SCT and more information about their supply chains. It is also possible that companies have SCV practices only planned or in the initial stage of development, and there is not much yet to be transparent about. However, it is unlikely that companies would refrain from sharing established practices in their reports. Therefore, it can be inferred that either these practices are in their initial phases or have not yielded significant results yet. Alternatively, companies may be hesitant to make claims of having supply chain visibility due to concerns about reputational risks.

One major problem identified during data collection is the overall confusion about the terms. SCV, SCT, and traceability are used interchangeably in many companies' reports, thus this creates complexity in analyzing the information. It may be the result of companies approaching SCV/SCT as one process, without separating it into internal and external components. Overall, in this thesis most of the conclusions are provided towards both concepts as they are tightly connected (see more in section 5.2.7.).

Two theories were applied to this research: multi-tier supply chain theory (MTSC) and complex adaptive systems (CAS). MTSC views SSCM as a linear process, where specific factors influence the choice of strategy. This study used factors from MTSC theory to highlight why companies bother to approach SCV and SCT in their SSCM practices, but due to the limited scope of the study and qualitative character of the research, it does not provide the answer on how each of the factors influences the choice of approach. Another reason for that is companies do not actually choose one single approach, but either *don't bother* for minerals with low criticality or stakeholders' pressure and combination of *direct, indirect,* and *work with third parties* approaches for the critical minerals. So in this case, while the MTSC framework provides a good starting point for the analysis, it does not provide a clear differentiation between different strategies. In practice, it seems that companies try to use everything to achieve an acceptable result, considering the resources available. This is also a consequence of the complexity and diversity of supply chains, where a single distinct approach is unrealistic in actual practice.

CAS theory can help to analyze the complex mechanisms of supply chains, but in practice, it is rather abstract and difficult to grasp without deep dive into the theory. One of the reasons is the use of complex terminology to describe the theory. Researchers may need significant time to understand the intricacies of each component of CAS and struggle to apply it practically. Paradoxically, attempting to explain the complex system using unfamiliar terms may make even simple explanations more complicated for general readers. This further complicates data

collection when engaging with practitioners, as they may not be familiar with technical terms like "rugged landscape". However, if the researcher translates these terms into simpler language or allows practitioners to express concepts in their own words, there is a risk of obtaining interpretations that may differ significantly from the intended meaning of the technical term. Therefore, there is an opportunity to further develop this theory to enhance clarity and make it more accessible to a broader audience.

6.3. Implications for Research and Practice

This research provides an extensive overview of the current state of SCV and SCT practices in minerals supply chains, along with insights into how these practices are integrated into SSCM and the factors that influence their implementation based on MTSC theory. By employing CAS theory, this study delves deeper into understanding how supply chain complexity impacts the feasibility of SCV and SCT practices. Through interviews with practitioners, valuable insights into the challenges associated with implementing SCV/SCT practices have been gathered, highlighting important areas that need to be addressed.

While academic literature predominantly focuses on the downstream perspective and focal companies (Hofstetter & Grimm, 2019; Sodhi & Tang, 2019), the role of midstream and upstream actors in supply chains remains relatively underexplored. This research underscores the significance of including midstream and upstream actors and considering their interests in the implementation of SCV and SCT practices. Further research is needed to better understand the specific challenges and opportunities that exist within these segments of the supply chain. The findings of this thesis highlight the importance of multi-stakeholder collaboration as a crucial approach to overcoming the challenges associated with SCV and SCT implementation, which was also highlighted in several academic articles (Garcia-Torres et al., 2022; Grimm et al., 2014; Hofstetter & Grimm, 2019). The study underscores that successful adoption of these practices requires collaboration and cooperation among diverse stakeholders. Further exploration into the key success factors and necessary conditions for effective multi-stakeholder collaboration would greatly contribute to advancing the field. Additionally, there is a notable lack of research on the integration of new technologies within existing business structures, particularly in the context of SSCM (Ebinger & Omondi, 2020). Given the evolving landscape of technology, it is imperative to focus on how to foster the integration of new technologies in supply chain processes, including SCV and SCT. Further studies dedicated to understanding the opportunities and challenges associated with integrating new technologies within the existing business structures will be essential for driving innovation and enhancing the effectiveness of SSCM practices.

There are several important questions raised by practitioners that warrant further exploration in academic research to support the implementation of SCV and SCT practices. Firstly, the issue of cost and financial responsibility for SCV and SCT implementation arises. Practitioners question who will bear the expenses associated with implementing these practices. Are there enough consumers willing to pay a premium for traceable products to support the initial implementation of traceability schemes? Understanding the business case and financial implications for supply chain actors is crucial to determine the feasibility and sustainability of SCV and SCT initiatives.

Secondly, practitioners raise concerns about how to effectively respond to stakeholder pressure for transparency. Are stakeholders genuinely prepared for the level of transparency that SCV and SCT practices entail? Will they be willing to acknowledge the current failures within supply chains and allow companies time to rectify them before resorting to public shaming or cancelation campaigns? Exploring stakeholder readiness and receptiveness to transparency

initiatives can provide valuable insights into managing stakeholder expectations and mitigating potential reputational risks.

Furthermore, the transformation of supply chains is a significant challenge. The existing structure of supply chains is not designed with visibility in mind. Implementing SCV practices can bring to light inefficiencies and raise questions about the overall effectiveness of supply chains. This may necessitate a complete reshaping of supply chains, and there is no clarity if the benefits can overcome the consequences of such changes. It is crucial to further explore the connection between SCT and business goals to understand how supply chains can be transformed without jeopardizing the interests of all actors. Addressing these questions through rigorous academic research will contribute to a more comprehensive understanding of the implementation challenges and potential solutions for SCV and SCT practices.

This research offers a practical perspective by providing an overview of the current practices and tools available for companies interested in implementing SCV/SCT in their supply chains. The thesis outlines the critical elements that are crucial to consider during the implementation process, enabling companies to make informed decisions and take appropriate actions. By presenting a comprehensive overview, this research equips companies with valuable insights and knowledge necessary for successful SCV/SCT adoption. Furthermore, the research sheds light on the challenges that companies may encounter on their journey to establish SCV/SCT practices. By identifying and illustrating these challenges, companies can gain a deeper understanding of the potential obstacles they may face. This awareness allows companies to anticipate and prepare for these challenges, improving their chances of effectively addressing them.

Additionally, the research highlights the early stage of the field and the opportunities for companies to actively participate in market development through collaborations. As technology providers are still in the pre-competitive stage, there is significant scope for collaborations, pilot projects, and further testing and development of technologies. This presents an opportunity for companies to tailor the implementation of SCV/SCT tools to their specific demands and requirements. By engaging in collaborative initiatives, companies can contribute to the advancement of SCV/SCT technologies and shape their development to better align with their supply chain needs.

Based on the challenges and insights gained from recent cases of implementing SCV and SCT practices in multi-tier supply chains of minerals, the following recommendations can be formulated to enhance SCV and SCT adoption:

- Companies that proactively prepare themselves early will gain a competitive advantage in the future. As pressure from regulators, stakeholders, and sustainability indicators continues to mount, companies need to anticipate and address these emerging requirements. For instance, battery supply chains are already facing upcoming regulations, prompting companies to invest in transformative measures that align with future expectations.
- Identify and collaborate with supply chain actors that share a common vision for visibility and sustainability. It is crucial to find partners at all levels of the supply chain who are already committed to sustainability and are eager to achieve greater market share by eliminating actors engaged in unethical practices. By uniting with like-minded partners, companies can collectively drive the adoption of SCV and SCT practices throughout the supply chain.
- Explore strategies to streamline supply chains and optimize their size. To optimize supply chains, it is important to identify opportunities to eliminate unnecessary

intermediaries and establish more efficient and transparent processes. This can enhance traceability, reduce complexities, and promote sustainability along the supply chain. Also, increased efficiency may create a business case for the company in further implementation of SCV/SCT practices.

- Foster collaboration and provide platforms for testing and developing new technologies that cater to companies' needs. Embracing innovative solutions can significantly support the implementation of SCV and SCT practices. By creating spaces for experimentation and advancement, companies can harness the potential of emerging technologies to enhance supply chain visibility, traceability, and overall sustainability performance.

Before adopting SCV/SCT practices, it may be useful to answer the following questions:

- What are our goals for introducing SCV and SCT practices? Do we aim for a minimum compliance level, want to compete with industry peers, or want to achieve systematic changes that align with our values?
- What minerals supply chains are the most critical for us? Companies may use the analytics and risk management tools provided by industry associations that will help identify priorities.
- What is the current state of visibility in these supply chains? What data do we already collect from our suppliers? How much information do we have on lower tiers?
- What actors in these supply chains can see value in increased visibility and transparency? What actors will resist the most?
- Are there multi-stakeholder collaborations in these supply chains that tackle SCV/SCT issues? Are there such collaborations in other supply chains that can share lessons learned and best practices?
- Is there internal capacity and readiness to test new solutions and practices without the expectation of fast results? Are there people inside the company with an entrepreneurial mindset and a mandate to lead changes?

These questions may be a starting point for companies to start their journey to SCV and SCT.

7. Conclusion

This thesis research examines the process of improving sustainability performance in multi-tier supply chains of large multinational companies. Transparency and visibility are crucial for implementing sustainability standards throughout the supply chain. Supply chain visibility (SCV) and supply chain transparency (SCT) are increasingly important for companies to stay competitive and meet stakeholder demands. Without SCV, companies are limited to their immediate suppliers and unable to manage risks and impacts across their entire supply chains. SCT enables companies to demonstrate high sustainability standards and responsible sourcing practices for materials used in their products. However, achieving SCV and SCT poses challenges due to systemic issues in supply chains. Specifically focusing on minerals supply chains known for human rights violations and environmental impact, this study explores the factors driving or hindering SCV and SCT implementation and evaluates their benefits and limitations for the SSCM.

The objective of this research is to examine the drivers, barriers, necessary conditions, available technologies, and the benefits and limitations of SCV/SCT for sustainable supply chain management (SSCM). This study employs a qualitative research design incorporating elements of ethnography and case study methodologies. The primary sources of data for the study consist of 47 published documents from 16 companies operating in the automotive, electronics, consumer goods, and industrial goods industries. Additionally, 5 webinars and 10 reports from industry associations and consultancies were utilized. The perspectives of practitioners were gathered through 7 interviews. To organize the collected data from multiple sources, a coding system was developed based on the literature review and theoretical frameworks.

RQ1: what role do SC visibility and transparency play in the SSCM process

SCV and SCT are becoming increasingly important for companies to maintain competitiveness and meet the demands of stakeholders. Without SCV companies know only their direct suppliers and cannot manage risks and impacts occurring in their full supply chains as is increasingly required by new due diligence regulations. SCV enables companies to pinpoint hotspots and take targeted actions to improve sustainability performance. SCT relies on SCV to assess risks and gain control before achieving transparency. SCT allows assuring stakeholders of high sustainability standards and responsible sourcing of all materials used in products. However, achieving SCV and SCT can be difficult due to the systematic problems within supply chains. Taking a CAS perspective on mineral supply chains can help to understand and anticipate these problems and dynamics better. Both SCV and SCT aim to reduce supply chain complexity, enhance connectivity, and reduce autonomy. In an unpredictable and evolving environment, visibility is crucial for making timely strategic decisions.

RQ2: what approaches do large multi-national companies implement to achieve SC visibility and SC transparency and what different factors influence a company's choice of approaches to SCV and SCT

Current practices do not allow for achieving full supply chain visibility. They only allow for covering high-priority suppliers in high-priority mineral supply chains and managing risks to a certain extent. The majority of the studied companies use an indirect approach when working with their sub-suppliers, which means that the success of existing tools relies heavily on the willingness of suppliers to transmit requirements further down the supply chain and ensure compliance with them by their suppliers and sub-suppliers. In addition, available tools for SCV and SCT do not cover the whole supply chain and all the indicators required by regulations and stakeholders. Another problem, most tools only provide a snapshot of the supply chain state at one moment in the past and are not able to capture the supply chain dynamics and complexity.

Moreover, their success depends on the willingness of suppliers to transmit requirements further down the supply chain and ensure compliance with them by their suppliers and sub-suppliers.

New technologies such as blockchain, AI, and digital twins have the potential to move SCV and SCT to a new level, allowing for more data to be collected and processed reliably. This includes data on the origin, chain of custody, and sustainability indicators that can be seen in real-time. However, it still relies heavily on the willingness of supply chain actors to cooperate, create trust, and change existing practices. Moreover, it is still necessary to have an established assurance process for supply chain actors before this data is collected and processed using digital technologies and invest in the development of suppliers with low sustainability standards. and invest in the development of suppliers which are not compliant with the focal company's sustainability standards. There is also a growing need for continued exploration of digital technologies for SCV/SCT based on a collaboration of supply chain actors and third parties that can make these initiatives scalable and applicable to multi minerals supply chains.

Several important factors influence the choice of approaches to SCV and SCT. First, it depends significantly on the regulations in force or expected to come shortly. Second, high stakeholder pressure for SCT creates stimuli to develop it and thus develop SCV, but with the proper level of caution so as not to cause more reputational risks and negativity from the stakeholders than in the absence of supply chain information. Third, various factors associated with each mineral's supply chain, such as criticality, level of dependence, and power dynamics, influence the prioritization of implementing SCV and SCT practices. Given the absence of readily available tools and technologies in the market, companies are required to experiment with solutions, navigate challenges, and gauge the responses of supply chain actors.

RQ3: what are key challenges and success factors in the process of establishing SCV and SCT

Achieving SCV and SCT is a complex undertaking that presents various challenges for companies operating in global supply chains. One prominent challenge is the difficulty of involving sub-suppliers in SSCM practices, including SCV and SCT. Companies often rely on their direct suppliers to promote sustainability further up the supply chain, leading to limited control over sub-suppliers and their practices. Systematic problems within supply chains also hinder SCV and SCT implementation. The current design of supply chains does not readily accommodate visibility. Competitiveness among supply chain actors often relies on information imbalances, protecting commercial details about suppliers, product sources, and specific deal characteristics. This information disparity creates resistance towards SCV and SCT implementation, necessitating additional efforts to overcome challenges. Many middle actors are resisting visibility as some of them are likely to be removed from supply chains when visibility leads to supply chain optimization.

While stakeholders demand greater transparency and disclosure, increased transparency can result in heightened scrutiny and pressure. Non-governmental organizations (NGOs) and stakeholders utilize transparency as a means to demand further disclosure and action, perpetuating a cycle of escalating demands. In addition, addressing supply chain issues, enhancing technological capabilities, and processing vast amounts of information demand substantial additional resources and it is still unclear how these costs will be shared. Furthermore, the lack of robust business cases outlining the advantages of SCT in minerals supply chains further complicates the adoption of SCT practices.

The prevailing approach to SSCM has been based on the belief that suppliers and sustainability concerns can be fully known and controlled. However, this thesis reveals that viewing mineral

supply chains as complex adaptive systems provides a deeper understanding of the origins of emerging issues and dynamics, and offers strategies for addressing them, even in situations where these dynamics cannot be predicted in advance. The current supply chain system is not in the optimal stage and does not respond adequately to environmental pressures, making changes unavoidable. Supply chains both react to environmental pressures and create them, so more visibility can lead to higher pressure for visibility and transparency. SCV is a small change, but it will lead to bigger system changes, resulting in completely new supply chains that are more efficient and sustainable. Visibility is not the end state of the system, but a process of many steps and actions. Companies can already prepare for the coming changes and create benefits.

Achieving SCV and SCT necessitates extensive collaboration and trust among supply chain actors. Implementation of SCV and SCT practices requires collective agreement on operational mechanisms, cost sharing, market functioning, and standards. Also, the collaboration will allow for the sharing of investments and risks associated with testing new technologies needed for SCV and SCT. However, supply chains are already changing, and many factors will continue to drive the system to the new state, where SCV and SCT are necessary characteristics of the supply chain. There are actors on all levels of supply chains that share the same vision of supply chain visibility and sustainability and are interested in getting more market share by eliminating actors with low practices. Those who are not following the systems' new practices may be excluded. Pressure from the environment will continue to increase, from regulators and other stakeholders, from GHG emissions reductions, and human rights protection in the supply chains to other sustainability indicators.

This research has **implications for both research and practice**. Firstly, it provides a comprehensive overview of the current state of SCV and SCT practices in minerals supply chains, offering insights into their integration within SSCM and the influencing factors. The application of MTSC and CAS theories enhances the understanding of supply chain complexity and its impact on SCV and SCT feasibility. The identified challenges through practitioner interviews highlight key areas that need attention during implementation, informing companies of potential hurdles and allowing for better preparation. Secondly, the research emphasizes the underexplored role of midstream and upstream actors in supply chains. It calls for further exploration of their interests and challenges concerning SCV and SCT practices, expanding the focus beyond focal companies. Multi-stakeholder collaboration emerges as a crucial approach to address the challenges of implementation, necessitating research into success factors and conditions for effective collaboration. Additionally, understanding the opportunities and challenges of technology integration is essential for enhancing supply chain effectiveness and promoting innovation.

From a practical standpoint, the research equips companies with a practical perspective on SCV and SCT implementation, offering an overview of existing practices and tools. It identifies critical elements to consider during the implementation process, empowering companies to make informed decisions and take appropriate actions. By highlighting the challenges faced by companies, it enables better preparedness and the ability to proactively address obstacles. Learning from the experiences of others who have tackled similar challenges serves as a valuable resource for companies seeking to implement SCV and SCT practices.

In conclusion, SCV and SCT have emerged as essential components for achieving sustainability goals and meeting the increasing demands of stakeholders for responsible practices throughout the entire supply chain. However, the implementation of SCV and SCT is a formidable challenge, and there are currently no established best practices. Nevertheless, the landscape is evolving, with numerous collaborations and projects dedicated to addressing this problem. By actively engaging in these initiatives, companies can contribute to the advancement

of SCV and SCT practices. Increased participation will generate greater attention from customers, heightening the demand for responsible practices. This, in turn, will accelerate the maturation of technologies and approaches, leading to systemic changes that foster sustainability and responsibility. While the path to achieving SCV and SCT remains complex, the collective efforts of companies, stakeholders, and technology providers hold the potential for transformative change. The ongoing collaborations and projects serve as catalysts for progress, driving the evolution of supply chains toward sustainability. As more companies join these endeavors, the momentum for responsible practices will grow, fostering a future where SCV and SCT are integral components of a responsible and sustainable supply chain.

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Appendix

Appendix I: List of interviews and webinars

Below the list of practitioners contributed to this study is provided. Practitioners' perspectives were collected during the interviews, and by watching webinars with the participation of practitioners from relevant supply chains.

Organization	**Interviewee role**	**Organization type in thesis context**	**Code for in-text reference**
Company A	Sustainability manager	Upstream company	A
Company B	Sustainability manager	Downstream company	B
Company C	Sustainability manager	Midstream company	C
Company D	Sustainability manager	Downstream company	D
Global Battery Alliance	Program manager	Stakeholder alliance	E
Company E	Founder	Technology provider	F
Company F	Founder	Technology provider	G

Webinar name	**Speaker**	**Organization type in thesis context**	**Name of an in-text reference**
Transparency and Traceability in Mining	Volker Krümpel is a Co-Founder of Minespider AG	Technology provider	Mines, 2021
The Benefits of Traceability in Supply Chains	Tara Norton, Chief Sustainability Officer Navico Group	Midstream company	Norton, 2021
Developing the World's First Successful End-to-End Battery Passport Pilot	Sven Jantzen, Director of Government Affairs, Umicore	Midstream company	RCS Global, 2023
Developing the World's First Successful End-to-End Battery Passport Pilot	Speakers from Re|Source, Kryha, RCS Global	Technology providers	RCS Global, 2023
Future-Proofing Supply Chain Due Diligence Management in the Digital Age	Alice Valvoda, Iain Fraser, RCS Global	Technology provider	RCS Global, 2022
Future-Proofing Supply Chain Due Diligence Management in the Digital Age	Erik Richter, Corporate Social Responsibility Correspondent, Stellantis	Downstream company	RCS Global, 2022
Future-Proofing Supply Chain Due Diligence Management in the Digital Age	Torsten Freund, the GBA	Stakeholder alliance	RCS Global, 2022
Enhanced Visibility in the Supply Chain World	Jerome Roberts, global vice president of marketing at Blume Global	Technology provider	SupplyChainBrain, 2022

Appendix II: Coding structure

- Sustainable supply chain strategy
  - Supply chain mapping and information collection
  - Requirements to sub-suppliers
  - Supply chain due diligence
  - Supplier development programs
  - Work with third parties
  - KPI
  - Non-compliance
- Factors
  - Power
  - Stakeholder pressure
  - Material criticality
  - Industry
  - Dependency
  - Distance
  - Knowledge resources
- Complex adaptive systems
  - Agency and schema
  - Emergence
  - Dimensionality
  - Dynamism
  - Collaboration
  - Connectivity
  - Rugged landscape
  - Non-random future
- SCV and SCT approaches / tools
  - Traceability
  - Other digitalization solutions (AI, digital twins, etc.)
  - Other transparency approaches (reporting, supplier lists publication)
- Challenges
- Benefits
- Key success factors

Appendix III: List of interview questions

The general list of interview questions is provided below. Before each interview, questions were tailored to the specific position of the interviewee in the supply chain (downstream, midstream, upstream, technology provider) and specific practical experience.

0. What initiatives do you have on SCV/SCT or what is your overall strategy towards SCV/SCT – *in case there is no data publicly available.*

1. How has the initiative on SCV/SCT evolved in your organization and /*emergence*/ what factors have driven its development? /*stakeholder pressure*/ How would you describe stakeholder pressure in your case?

2. /*material criticality*/ Why SCV/SCT is applied to the specific supply chain (mineral), and what were the decision-making factors for it? How is it connected with the overall SSCM strategy? /*dimensionality*/ Do you aim to have full control of this supply chain or allow any level of autonomy? /*dynamism*/ Is this supply chain fast-changing (with high supplier turnover)?

3. /*Agency*/ Which organizations in your supply chain drove the development of SCV/SCT projects? /*collaboration, connectivity*/ Does they approach it individually or used any form of collaboration? /*schema*/ Why did they drive this project, what are their motivations?

4. /*strategy*/ How downstream companies engage with sub-suppliers and third parties in your case? /*power*/ Do they have enough power to push changes across the supply chain? /*dependency*/ What is the level of dependency in your supply chain?

5. What were the necessary conditions for the development of the SCV/SCT project in your company? /*Knowledge resources*/ Did you have the necessary knowledge and capabilities, or you had to find it externally? Did you have full visibility of your supply chain before implementing the SCT project? /*rugged landscape*/ Why was it difficult to achieve SCV initially?

6. What are the benefits of the SCV/SCT solution in your case? Do these benefits surpass your costs?

7. What were the main results of the SCV/SCT project? What were the key success factors for SCV/SCT project?

8. How have your sustainability practices changed after implementing an SCV/SCT solution?

9. /*non-random future*/ Based on the drivers and factors that you see, how do you think SCV and SCT will develop in the next 5 years and what challenges are still needed to be solved? Will it stay the niche solution for the most critical SC or it will be scaled?

Appendix IV: List of SSCM practices for responsible minerals sourcing

Below the overview of all indirect measures is provided in order to form a basic understanding of the SSCM processes. This information is descriptive and will form a foundation for the further analysis of challenges and approaches to establish SCV/SCT.

The majority of studied companies use a **Code of Conduct (CoC) and other corporate standards** to pass their standards to suppliers and specify that suppliers shall establish the same standards towards their suppliers (ABB, 2019; Audi, 2021b; Caterpillar, n.d.; Philips, 2023; Samsung Electronics, n.d.; Siemens, 2023; Tesla, 2021; Toyota, 2021b; Volvo Group, 2022). The Obligatoriness of CoC clauses can vary from expectations to legal requirements. Examples of expectations include supervision and support - "the 1st-tier suppliers shall make every effort to supervise and support their supply chain and subcontractors so that they comply with the Guide" (Samsung Electronics, n.d.), communication and persuasion - "we expect our suppliers to adopt, implement and communicate to sub-suppliers their positions and policies regarding Conflict Minerals, and where possible, require their down-stream suppliers to adopt and implement similar positions and policies" (Caterpillar, n.d.). Some more strict requirements include: **obligation to cascade requirements to sub-suppliers** - "have established ethical, social and ecological minimum requirements in your supply chain, and your suppliers are legally bound to comply with them. You take suitable measures (e.g. Sustainability Self Assessments, on-site visits, and management talks) to ensure that your suppliers permanently meet the minimum requirements" (Siemens, 2023), **use of contractual clauses** - "Supplier shall ensure that all Requirements of this Supply Partner Code of Conduct are cascaded to and complied with within its own operations and by its own direct suppliers. This shall be ensured through proper contractual wording or a fully implemented supplier code of conduct. We also encourage each Supplier to work proactively in their supply chain beyond their direct suppliers to implement similar standards" (Volvo Group, 2022).

Companies may choose to establish more detailed **requirements for specific minerals supply chains and specific actors in supply chains**, for example: "All identified priority suppliers are requested to identify all 3TG smelters in their supply chain, and if they do not source directly from smelters, they are asked to pass on this request to their suppliers (who may have to pass it on to their suppliers, until the smelters are identified), cascade Philips' request to only source from RMAP (or equivalent) compliant smelters to their suppliers and ask them to do the same with their next tier partners" (Philips, 2021). Companies may request records that provide evidence for compliance with CoC, for example: "Suppliers must maintain accurate and up-to-date records of their compliance with this Code and all applicable laws and regulations. Upon request from Tesla to provide such records or internal policies and procedures, documentation must be shared promptly" (Tesla, 2021).

Questionnaire assessment allows to evaluate a big number of suppliers with small resources, as suppliers are evaluating their performance themselves based on the checklists provided by the focal company. Companies are using standard questionnaires (e.g. Responsible Business Alliance (RBA) questionnaire) or their own templates and processes. In many cases, there are no data quality or credibility checks, but it allows to define the most critical suppliers for which more in-depth evaluation can be performed (ABB, 2022). Questionnaires can be used to cover 100% of direct suppliers (Samsung Electronics, 2022), while audits can be conducted for 5-15% of suppliers that have gone through self-assessments (Siemens, 2023; Volkswagen Group, 2021b). In general, these assessments allow "identify their greatest social, environmental and ethical risks in supply chains, take action to remedy existing Code of Conduct violations, to assess risk management systems and identify gaps" (RBA Assessment Tools, n.d.).

Questionnaires can allow primary identification if critical minerals are in the supply chain as a first step toward establishing SCV. For example, the RBA questionnaire includes questions on conflict minerals identification in the supply chain (RBA Assessment Tools, n.d.).

In an *indirect* approach, companies **audit** their direct suppliers to ensure that sustainability requirements are passed upstream (Siemens, 2023; Volvo Group, 2021). Companies for audit can be selected using selection criteria or through random choice among specific groups (e.g. randomly selected suppliers among the top 90% of suppliers in terms of transaction amount) (Samsung Electronics, 2022). To strengthen their internal audit procedures, companies may use **external checklists and standards for audits** ("We thoroughly review each candidate's environment/safety and labor/human rights status using the internal checklist based on the criteria of the Responsible Business Alliance (RBA)" (Samsung Electronics, 2022), "Responsible Business Alliance's (RBA) Validated Assessment Program (VAP) as the basis for our audits. The RBA's VAP is an audit protocol globally recognized for its breadth of topics and stringent requirements for supplier completion. It covers nearly 200 checkpoints across labor, health and safety, environmental, ethical, and management system topics. Audits are conducted by independent third parties that are approved by the RBA, and all auditors must undergo training by the RBA on the audit standard and its implementation ensuring a globally and industry-wide standardized approach" (Tesla, 2021)), check suppliers' **certifications or external audits** ("reviews suppliers' ISO14001 (environmental management) and OHSAS 18001 (occupational health and safety) certification statuses", "independent external sustainability audits against one of the following sustainability and responsible mining standards: IRMA Standard, the Responsible Minerals Initiative (RMI) Responsible Minerals Assurance Process (RMAP), Towards Sustainable Mining (TSM) and/or the International Council on Mining and Metals (ICMM)" (Tesla, 2021), "As part of its efforts to promote RMAP-conformance among smelters, Sony identifies non-conformant smelters and works with them to gain certification" (Sony, 2022)). There is an opposite opinion from NGOs that certifications are not enough: "Certification is also not sufficient. Based on PACT's experience, it takes more than one-off checks. We need ongoing monitoring by trained individuals who will continuously be present and record and report various risks and support companies to mitigate those risks. Circumstances in mining communities are always changing, so this ongoing aspect is key. We need a continuing, proactive process to truly make lasting changes" (PACT, 2022).

Appendix V: List of collaboration partners for responsible minerals sourcing

The examples of organizations that are most mentioned for collaboration in responsible sourcing of minerals are provided in Appendix V.

Responsible business alliance (RBA) is the most mentioned partner for collaboration in minerals SSCM. RBA is "the world's largest industry coalition dedicated to corporate social responsibility in global supply chains" (*Responsible Business Alliance*, n.d.). Companies use a Code of Conduct, self-assessment questionnaires, checklists for suppliers' assessment, risk roadmap, and other risk assessment tools developed by RBA (BMW, 2021; Samsung Electronics, 2022; Sony, 2022). "The RBA's Validated Assessment Program is an audit protocol globally recognized for its breadth of topics and stringent requirements for supplier completion. It covers nearly 200 checkpoints across labor, health and safety, environmental, ethical, and management system topics. Audits are conducted by independent third parties that are approved by the RBA, and all auditors must undergo training by the RBA on the audit standard and its implementation ensuring a globally and industry-wide standardized approach" (Tesla, 2021).

RBA has established the **Responsible Minerals Initiative (RMI)**, which is "one of the most utilized and respected resources for companies addressing issues related to the responsible sourcing of minerals in their supply chains" (*Responsible Business Alliance*, n.d.). RMI's resources include: Responsible Minerals Assurance Process (3TG and cobalt), Risk Readiness Assessment, Minerals Reporting Templates (3TG and cobalt), industry-wide grievance mechanism, Reasonable Country of Origin Inquiry data, RMI Learning Academy, public global smelter/refiner lists, and a range of practical guidance documents for the industry" (*Responsible Business Alliance*, n.d.). "Philips used the "Smelter Look-up" in the Conflict Minerals Reporting Template and RMI smelter database information as a reference to compile the Philips Smelter List. Based on the CMRT "Smelter Look-up", Philips identified a total of 332 listed smelters in the supply chain out of the 349 names reported to Philips. According to the RMI smelter database information, among the 349 listed smelters, 15 have ceased or suspended operations" (Philips, 2021). **Responsible Minerals Assurance Process (RMAP)** is RMI's program that "uses an independent third-party assessment of smelter/refiner management systems and sourcing practices to validate conformance with RMAP standards. The assessment employs a risk-based approach to validate smelters' company-level management processes for responsible mineral procurement" (RMAP Assessment Introduction, n.d.). Smelters and refiners that have passed RMAP are publicly listed which helps to establish transparency in the supply chains. Companies may demand their suppliers to identify smelters and refiners in their supply chain, and accept only products that were acquired from the RMAP-certified actors: "We demand that our suppliers work only with smelters that have received RMAP certifications, and we halt transactions that include any minerals provided by non-RMAP-conformant smelters. By only using RMAP-certified smelters, we can ensure that the minerals we are sourcing have been mined ethically regardless of origin" (Samsung Electronics, n.d.).

The Initiative for Responsible Mining Assurance (IRMA) is a certification scheme for upstream suppliers – mining companies. It is an "independent third-party verification and certification against a comprehensive standard for all mined materials that provides 'one-stop coverage' of the full range of issues related to the impacts of industrial-scale mines" (Volkswagen Group, 2021a). IRMA provides "transparent and robust audit processes that emphasize community interviews". NGOs and communities perspectives "provide greater context on mining operations and the impacts of extraction, while also increasing accountability and identifying opportunities for improvement" (Tesla, 2021).

Drive Sustainability (DS) is "a partnership of ten major automotive brands - manufacturers of commercial and passenger vehicles (BMW Group, Daimler AG, Ford, Honda, Jaguar Land Rover, Scania CV AB, Toyota Motor Europe, Volkswagen Group, Volvo Cars, and Volvo Group) convened to take action for greater sustainability throughout the automotive supply chain" (Drive Sustainability et al., 2018). Volvo Group invites tier-1 suppliers to join partnership "to strengthen the dialogue, collaboration, and understanding in order to achieve common sustainable supply chains" (Volvo Group, 2021). DS also develops the **Raw Material Outlook Platform** – a value chain mapping and sustainability risk identification tool for 10 critical materials: aluminum/bauxite, graphite, iron ore, magnesium, manganese, molybdenum, nickel, RREs, tantalum and zinc with other raw materials are planned to be added later (Volkswagen Group, 2021a; Volvo Group, 2021). The Platform "provides a channel for engagement with other companies and stakeholders to identify collaborative actions for managing and mitigating risks in these supply chains" (Volkswagen Group, 2021a).

Global Battery Alliance is a stakeholder initiative that aims on creating a platform for stakeholder dialog to develop commonly accepted standards on traceability, enhancing circularity, measurement of sustainability indicators, and so on. It is also coordinating the development of the first Battery passport - a digital product passport that will provide customers with information on each battery's metal origin, recycled content, and sustainability performance. "Initiatives like the Global Battery Alliance are designed to help ensure more effective due diligence in raw materials sourcing. They're the ideal places to discuss questions like: What should apply specifically to our industrial sector? What can we all agree on? That's why all stakeholders need to be heard there, including civil society groups, scientists, and government representatives. If they all work together effectively, they will produce robust standards that can be put into practice" (Audi, 2021a). "Tesla's goal as part of the GBA is to advocate for high standards for responsible battery materials sourcing, align with EU regulatory requirements, and support the development of actionable guidance related to GHG emissions data collection, recycling, and in-country environmental and social projects" (Tesla, 2021).

There are an extensive number of organizations by region and by mineral that have similar goals in improving supply chain sustainability and transparency. Other mentioned partners for collaboration included: European Raw Materials Alliance (ERMA), European Partnership for Responsible Minerals (EPRM), International Council on Mining and Metals (ICMM), NGO Pact, Cobalt Institute, Aluminium Stewardship Initiative, the Responsible Lithium Partnership Initiative, Responsible Mica Initiative, Nickel Institute, The Copper Mark and others.

The list of mentioned collaboration platforms by mineral and available tools is provided below.

Table 0-1. Collaboration partners for different minerals

Mineral	Initiatives covering responsible sourcing of mineral	Available tools
Conflict minerals (3TG)	Responsible Minerals Initiative The International Tin Association The World Gold Council Conflict-Free Gold Standard	Assurance process Risk management tools Reporting templates Due Diligence Standard
Cobalt	Responsible Minerals Initiative Cobalt Institute Responsible Cobalt Initiative	Assurance process Risk management tools Reporting templates Due Diligence Standard
Nickel	Responsible Minerals Initiative	Assurance process

	Nickel Institute	Risk management tools Due Diligence Standard
Lithium	Responsible Minerals Initiative Responsible Lithium Partnership initiative	Risk management tools
Mica	Responsible Minerals Initiative Responsible Mica Initiative	Assurance process Risk management tools Reporting templates Due Diligence Standard
Copper	Responsible Minerals Initiative The International Copper Association The Copper Mark	Assurance process Risk management tools Due Diligence Standard
Aluminium	Responsible Minerals Initiative The International Aluminium Institute Aluminium Stewardship Initiative	Assurance Process (ASI) Risk management tools Due Diligence Standard

Source: (Cobalt Industry Responsible Assessment Framework (CIRAF), n.d.; Responsible Minerals Initiative, n.d.; The Copper Mark, n.d.)