

# A Critical Eye-Opener

Awareness and sense of urgency of Critical Raw  
Material supply risks in Dutch business

Thesis Industrial Ecology

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Universiteit  
Leiden





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by

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# Preface

Nearing the end of my thesis, I can say that I am very proud to have finished this research, but I could not have done it alone. Therefore, there are several people I would like to thank.

I had always hoped to find a company that shared my own curiosity, sustainability ideals, and the perception that companies can be a force for good. Therefore, I can say that I am very happy that in Copper8 I found the perfect company to do my thesis internship. A special thanks goes to my Copper8 supervisors, Stefan and Cécile, and the rest of the Copper8 family for their guidance, assistance, insights, laughs, and good times. In addition to receiving excellent supervision and advice during my thesis, my internship at Copper8 has expanded my perception of what a company can do to drive change in our society, which will be a lesson for life.

I would like to thank David Peck and Benjamin Sprecher for the warm welcome in their field of expertise and for their excellent guidance and advice when the trail seemed to be lost. Knowing very little about the topic of critical raw materials in advance, my curiosity was sparked daily, and it has been super educational to see the theoretically described importance of the topic unfold in real life. I hope this thesis can assist the movement aiming to get the topic on everyone's radar before the negative effects of unavailability truly hit our society.

Lastly, a special note of gratitude to my parents for their immeasurable support during my 22 years of education.

*David Spaargaren  
Delft, July 2025*

# Summary

This thesis addresses the challenge of low awareness and low sense of urgency regarding Critical Raw Material (CRM) supply risks among companies. Despite growing geopolitical tensions that put companies dependent on CRMs at risk, few companies seem to have implemented mitigation strategies. Part of this inactive attitude is due to a lack of understanding of possible impacts, the abstractness of the topic, and the uncertainty of the risks involved. Therefore, this research aims to answer the question: *How can awareness and the sense of urgency of CRM supply risks in companies be increased through a communication tool?*

This research adopts a pragmatic philosophy and an Action Research (AR) methodology, which means that a participatory and iterative approach to knowledge generation is applied in the creation of a communication tool. AR has been proven to be useful for the generation of knowledge for sustainability transitions, but never before had it been applied in the co-development and implementation of a communication tool in the field of CRM.

The first phase (SQ1) involves a comprehensive literature review, in which academic and gray literature is synthesised to establish a detailed overview of the CRM supply risks relevant for downstream companies in the Netherlands. This analysis confirmed that geopolitical tensions and over-reliance on a limited number of supplier nations are currently the most immediate and impactful risk factors, creating a high uncertainty of supply for many materials and products.

The second phase (SQ2) evaluates various communication tools used in a business context to raise awareness. Scenario planning (SP) is selected as the most appropriate tool due to its proven effectiveness in other risk contexts, its previous applications in the formation of a strategy in uncertainty, and its academic support. Drawing on theories of change management (Kotter, 1996a) and SP (Cairns & Wright, 2017), a 3-hour SP was designed. By adding an introduction to the SP format that summarises the findings of SQ1, the tool was structured to be accessible to participants without prior knowledge of CRMs. SQ3 outlines the final structure of the tool.

The final and central phase of the thesis consists of the evaluation of its effectiveness. A pilot study was designed with involvement of non-expert participants, which was used to generate practical insights and validate the concept of the workshop. This participatory approach aligns with one of the core principles of AR. Afterwards, the tool was implemented in a case study with a large Dutch company in the installation sector. Participants in both cycles participated in scenario exercises and collaboratively explored mitigation strategies. Data was collected using a mixed methods approach, including pre- and post-workshop questionnaires, semi-structured interviews, and in-workshop observations and worksheets.

The AR cycle findings show that the workshop is effective, as participants expressed that in their view, CRM risk topics shifted from being intangible to more clearly understanding what these risks entail and how they would affect their organisation. In addition, the participants expressed that they now felt a sense of urgency to mitigate the risks of CRM. Through strategy worksheets they collaboratively outlined the first steps towards initiation of mitigating strategies, including plans for internal material assessment and sectoral cooperation, showcasing a shift from inaction to proactive engagement.

The qualitative results provide strong support for the central proposition of this thesis, although the quantitative data showed more modest changes, such as limited shifts in how CRM supply risks were perceived relative to other strategic risks. Therefore, it is recommended to further investigate quantitative methods of risk awareness assessment.

This research concludes that the novel condensed form of the SP workshop can be a valuable tool for companies willing to create internal awareness for CRM supply risks and use this awareness to cooperatively set the first steps towards implementing mitigation strategies. In conclusion, the developed communication tool can help companies reduce their CRM dependence and demand, mitigate future risks, and build toward a more circular and sustainable future.

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# Abbreviations

Abbreviation	Definition
AR	Action Research
AW	Awareness
CBAM	Carbon Border Adjustment Mechanism
CRMA	Critical Raw Material Act
CRM(s)	Critical Raw Material(s)
CSRD	Corporate Sustainability Reporting Directive
CT	Communication Tool Acceptance
ESG	Environmental, Social, and Governance
EU	European Union
EC	European Commission
EZK	Ministry of Economic Affairs and Climate Policy
GE	General Electric
GHG	Greenhouse Gas
GSCP	Green Supply Chain Practises
HCSS	The Hague Centre for Strategic Studies
HHI	Herfindahl-Hirschman Index
IE	Industrial Ecology
IISS	International Institute for Strategic Studies
ILM	Intuitive Logic Method
INT	Interview
KPI	Key Performance Indicator
LP	La Prospective
NGO(s)	Non-Governmental Organization(s)
PEOU	Perceived Ease of Use
PESTL	Political, Economic, Social, Technological, Legal, Environmental
PU	Perceived Usefulness
PWQ	Pre-Workshop Questionnaire
PoWQ	Post-Workshop Questionnaire
REE	Rare Earth Elements
RVO	Netherlands Enterprise Agency
SC	Supply Chain
SCRM	Supply Chain Risk Management
SMEs	Small and Medium Enterprises
SP	Scenario Planning
SQ	Sub Question
SRM(s)	Strategic Raw Material(s)
ST	Organizational Strategy
SU	Sense of Urgency
TAM	Technology Acceptance Model
WGI	World Governance Index
WTO	World Trade Organisation

“



# 1

## Introduction

The very materials supporting Europe's green and digital transitions are now a source of problematic geopolitical vulnerability. Despite this, many companies remain unaware of the risks embedded deep within their supply chains. In a society that has to make several transitions, such as the decarbonisation of the energy system, innovative companies are the drivers of materialising the necessary change. For their products and services, many materials with unique properties are required. These materials were used to be extracted and produced all over the world, with intricate trade routes that supplied the European economy with all its necessary materials. As global shifts in production have led to a limited number of supplying companies and countries, the Netherlands is almost completely dependent on imports for many products and materials.

In recent decades, China has become indispensable in many of these supply chains (HCSS, 2024). Having few suppliers of specific materials creates a great dependency on these trade relationships, an issue that is among the top priorities of the European Union (Commission, 2024). In addition to a general increase in material demand due to growth in the worldwide population (Council & Markit, 2019), the demand for many materials is increasing rapidly due to the transition to energy and the growth of defensive budgets (Girardi et al., 2023; Girtan et al., 2021). The European Commission is monitoring the security of raw material supply. Every three years, the materials with the highest combined economic value and supply risk are listed. The 2023 list contains 34 materials, which in the rest of this thesis are referred to as the Critical Raw Materials (CRM). Eight of these are labelled as Strategic Raw Materials (SRMs). Although they are less vulnerable to immediate supply risks, they are included due to their importance in the energy transition, digitalisation, defence, and aerospace (Commission, 2023b).

In the field of CRM, the emphasis is on material acquisition and strategic autonomy from a government perspective, while the role of companies in managing CRM-related risks and opportunities receives comparatively less attention (Griffin et al., 2019). However, companies are key actors in supply chains and are therefore directly exposed to operational, financial and reputational impacts of CRM dependence (Kyngdon-McKay, 2015). This is not limited to large corporations, as Small and Medium Enterprises (SMEs) dominate much of the global economy and play a key role in the electronics, automotive, and medical technology industries (Kyngdon-McKay, 2015). However, there is limited research available on how SMEs manage CRM usage. The materials or products that are critical differ by industry and even by company. Although often used by industry, the EU Critical Raw Materials list is not intended for firm-level application. As noted in Goddin (2019), the lists were primarily intended to inform regional policy, foreign affairs, and investment strategies rather than to serve in supporting design and engineering choices, or internal risk management. Although the EC assessment focusses on a specific set of raw materials in its criticality assessment, every material, product, or part required for the operations of a company can be considered critical to that specific company (Gardner & Colwill, 2018; Graedel & Reck, 2016).

*Terminology note: for readability, the terms company, firm, organisation, and enterprise are used interchangeably throughout this thesis. All refer to self-governing commercial operating business entities, unless otherwise stated.*

It has been observed that companies have insufficient awareness of their vulnerability to supply chain

disruptions (Goddin, 2019; Kyngdon-McKay, 2015). This leaves many manufacturers unaware of whether their operations are at risk due to the dependency on critical materials for production or operations (Gardner & Colwill, 2018). Critical materials are often vital elements in companies' value chains, but traditional supply chain management strategies cannot adequately address their supply risks (Gardner & Colwill, 2018).

The risks associated with CRM dependence have increased in recent years. Geopolitical tensions have increased, decreasing the security of the supply chain of many materials. Sudden trade restrictions, such as the export restrictions of tungsten and Rare Earth Elements (REE) from China in April 2025 show the vulnerability of the supply of these materials (Baskaran & Schwartz, 2025).

Currently, most CRM supply chains are linear, with recycling rates for some materials close to 0 (Commission, 2024). The extraction and processing of CRM cause significant environmental problems, including habitat destruction, high GHG emissions, intense energy and water use (Goddin, 2019), toxicity, and human rights abuses (de Pooter et al., 2022). Enhanced recycling could solve many of these problems, as it would reduce the demand for raw materials and is far less energy intensive (Mendis & Singh, 2013). Going towards a circular system would reduce negative effects associated with CRM, but requires large investments and is still far from integrated in most sectors.

Both the short-term risk of supply chain disruption, the long-term increase in demand, and the negative externalities of CRM show the need for companies to reduce their usage of imported CRM. The inaction of companies on CRM issues aligns with findings from previous management studies, which conclude that the biggest threats to an organisation are often visible well in advance; yet, people fail to act until it is too late (Bazerman & Watkins, 2004). However, previous research by Sheffi and Rice Jr (2005) has tracked the typical firm response to supply disruptions. Based on that, Griffin et al. (2019) shows that proactive identification of substitutes or development of new materials or technologies could substantially reduce the drop in firm performance and its duration.

Therefore, companies at risk of CRM supply risk disruptions should change their attitude towards these risks. Kotter (1996a) leading work on change within companies shows that without a sense of urgency towards an issue, it is unlikely that change will be achieved successfully.

In summary, this leads to the following problem statement:

Companies are dependent on products containing Critical Raw Materials (CRM), which have a limited number of suppliers and therefore a high supply uncertainty. Currently, there are few tools available to increase awareness and the sense of urgency in companies. Evidence suggests a low sense of urgency towards CRM supply risks in companies and limited awareness of the risks involved. If a sense of urgency could be created, companies could initiate mitigation strategies which mitigate supply uncertainties and reduce CRM demand.

## 1.1. Research aim and questions

The objective of this thesis is creating a communication tool for this purpose, and evaluating its effects on participants' awareness and sense of urgency towards CRM supply risks.

The thesis is structured around the following Research Question:

### Main Research Question

**How can awareness and the sense of urgency of Critical Raw Material (CRM) supply risks in companies be increased through a communication tool?**

This question will be answered through the following sub-questions:

SQ1: What are the main supply risks associated with companies' dependence on CRMs?

SQ2: What communication tools can increase risk awareness in companies?

SQ3: What is the structure of the CRM awareness tool?

This thesis follows a sequential exploratory design, adopting a pragmatic philosophy and an Action Research (AR) approach, as substantiated in the Theoretical framework in chapter 3. The research is structured in four phases, the first three addressing a specific sub-question, and the fourth evaluating the effects of the implementation. A detailed visual representation of this research framework is presented in the Methodology, Chapter 4.1. The final goal of this thesis is to create and validate a practical tool which can be used by companies to create internal awareness of CRM supply risks.

## 1.2. Scope and delimitations

Temporal scope: short-term risk

The central aim of this research is to increase the sense of urgency regarding CRM risks. While criticality assessments can span decades, such long-term horizons often increase psychological distance, causing managers to perceive risks as abstract, distant, and therefore non-urgent (Spence et al., 2012). Choosing a short time scale can help overcome the urgency barrier. Therefore, this study adopts a time interval of 1 to 5 years, a time frame suggested by Graedel et al. (2012) as most relevant for corporate strategy and investment cycles. This specific scope is designed to frame CRM risks not as a distant generational challenge but as a clear present issue that demands immediate attention and fits within standard business planning cycles.

Geographic scope: the Dutch context

This research is scoped to companies operating in the Netherlands to enhance the study's internal validity and practical relevance. The Dutch commercial landscape is characterised by companies located downstream in global value chains, providing a representative context for studying CRM risks that are often indirect and hidden. This focus ensures that the findings are directly applicable to the commissioner (Copper8) and provide actionable insights for downstream users of products containing critical raw materials.

## 1.3. Relevance to Industrial Ecology and Society

### 1.3.1. Societal and Environmental relevance

This topic is of social relevance because of the combination of an increasing dependence on certain materials in the energy transition, while geopolitical tensions are rising globally. CRM dependence could become the bottleneck of the energy transition, as material demands are expected to grow even further in the coming years (Gielen, 2021). In addition to that, CRMs are lagging behind recycling targets, which is harmful to circular economy goals. CRM production is highly energy intensive, and since most production occurs in China where most of the power generation is powered by coal, it is associated with high emissions (Cohen, 2023). The refinement of CRMs, such as lithium, is estimated to be associated with up to 4x as much emissions as in other countries (Cohen, 2023). In addition, shipping materials from all over the world to China and then back to Europe is a carbon-intensive process. These environmental impacts present a paradox, as many CRMs are vital for sustainable technologies such as electric vehicles and renewable energy, but at the same time they exacerbate the climate crisis these technologies aim to mitigate.

Lastly, the mining of critical materials has been associated with land loss, displacement, and human rights abuses against indigenous communities (IRENA, 2023). However, if managed responsibly, the energy transition can promote inclusivity and stability through international cooperation (IRENA, 2023).

### 1.3.2. Industrial Ecology perspective

This thesis adopts an industrial ecology (IE) perspective on the problem of critical raw material usage. This perspective is highly relevant due to several factors, which align with the core pillars of IE:

1. **Multi-disciplinarity:** IE, by its nature, looks at topics from a multidisciplinary view. In the case of CRM, the topic and its related problems cannot be understood from a singular perspective. Rather, they sit at an intersection of global supply chains, technological innovation, environmental studies, and geopolitical dynamics. Integration of insights from material science, supply chain management, management studies, environmental studies, and finance helps better understand the topic, and choose the most successful approach in driving change. The IE perspective allows for a systemic analysis of these interdependencies, which can be used to create evidence-based

strategies that can support both policymakers and industry actors in navigating the uncertain raw materials landscape.

2. **Interconnected systems:** IE treats supply chains as interconnected systems: Rather than looking at mining, refining, manufacturing and end-of-life in isolation, IE encourages viewing the entire CRM supply chain as a complex industrial ecosystem. This allows for a holistic understanding of how materials flow, where dependencies and bottlenecks are located, and how disruptions in one part can impact the entire system. Representatives from the companies contacted worked in various departments, including sustainability, finance, supply procurement, and upper-management.
3. **Material and energy flows:** This research uses IE principles to track the flows of specific CRMs through the economy, from extraction to end of life. This helps identify bottlenecks and discuss possibilities of mitigation strategies in altering these flows, e.g. through increasing circular flows through recycling.
4. **Circularity:** The thesis aims to support a tool that can be used to evaluate mitigation strategies to promote circularity. This explores the potential of recycling CRM-containing products or utilizing industrial waste streams (secondary production) to reduce reliance on high-risk primary extraction and 'close the loop', mimicking natural ecosystems.

# 2

## Literature review

### 2.1. Introduction and methodology

This chapter presents a review of the existing literature that forms the theoretical and empirical basis for this thesis. It explores key concepts and theories related to Critical Raw Materials (CRMs) and their associated risks, and it explores the possible mitigation measures and drivers for initiating these in a business context.

Academic literature was a primary focus, identified through comprehensive searches in databases such as Google Scholar and the TU Delft and Leiden University repositories using keywords including “critical raw materials”, “Critical minerals”, “CRM”, “risk”, “disruption”, “supply chain risk”, “company”, “organisation”, “corporation”, and “business”.

Beyond academic research, insights were drawn from reports and publications by governmental institutions. Relevant company reports were also consulted to understand industry perspectives and practices on material sourcing and risk management. A deeper analysis on CRM supply risk and mitigation action is provided in Chapter 5, responding to SQ1.

To broaden the search and uncover relevant works, a backward snowball technique was applied, tracing citations in key articles. Furthermore, AI-driven academic search platforms, such as Elicit and Gemini, were leveraged to explore interconnected research areas and identify potentially overlooked studies that could offer new insights.

The subsequent sections of this literature review provide a comprehensive overview of CRM criticality, the need to urgently address risks in a business context, and the intersection of these topics within the context of CRM supply chain resilience.

### 2.2. Understanding CRM criticality and supply risk

#### 2.2.1. Defining critical raw materials

The concept of ‘critical materials’ dates back to the 1930s. The term was introduced in the United States in 1939 as part of the original stockpile legislation, after which it was reported in several reports from the 1950s to the 1980s (Dewulf et al., 2016). The term refers to materials essential to the economy but at risk of supply disruption. Definitions and assessments differ between regions and times, which shows that criticality is a dynamic property influenced by supply, demand, and context. Assessments are performed to inform which materials are critical to the tailored to the needs of the assessing body. The next section will elaborate on the topic of criticality assessments.

#### 2.2.2. Methodologies for criticality assessment

Criticality assessments are intended to facilitate the prioritisation of materials by assessing the relative risks of each material. Criticality is often assessed and graphically displayed on two axes: (1) supply risk and (2) impact or vulnerability. One of the earlier assessments by National Research Council (2008) evaluated non-fuel materials based on two variables, importance of uses, and availability. Most analyses published later are variations of this two-axis model. However, as stated by Achzet and Helbig (2013)



who studied 15 different assessments, there were large differences in the included indicators, resulting in different sets of materials being assessed as critical. Some, such as the methodology of Graedel et al. (2012), include a third axis (e.g. environmental impact).

Primary axis of criticality assessment: supply risk

The first axis measures supply risk, so a score on this axis tells the likelihood that supply is interrupted. There is general consensus on the first axis, although there are differences in its underlying components and computations (Dewulf et al., 2016). The methodologies describing this axis often separate a short-term and a long-term component. For the short-term component, Achzet and Helbig (2013) found that the indicators most frequently observed are country risk and country production concentration. For the long-term component depletion time, by-product dependency, demand growth projections, and recyclability are important factors.

#### Physical availability

Quite a lot of research is focused on the long-term physical availability of CRMs, considering constraints such as mining capacity, known geological reserves, and the feasibility of new exploration projects (Graedel et al., 2015; Yavor et al., 2021). The demand for many CRMs is projected to increase significantly, mainly driven by the energy transition (Watari et al., 2020). Supply often struggles to scale rapidly due to long lead times for new mine development which range between 4-20 years, insufficient investment, local opposition, and declining ore grades in existing mines (de Pooter et al., 2022; Sprecher et al., 2017).

In the academic literature, two main perspectives dominate discussions on the long-term availability of minerals: the fixed stock paradigm and the opportunity cost paradigm (Poulton et al., 2013; Tilton, 2010). According to the fixed stock paradigm, the depletion of mineral resources is just a matter of time, as the earth is finite and therefore the mineral supply is also finite (Tilton, 2010). The perspective of opportunity cost suggests that during times of mineral scarcity, rising prices serve as a catalyst for technological innovation and progress (Graedel et al., 2014).

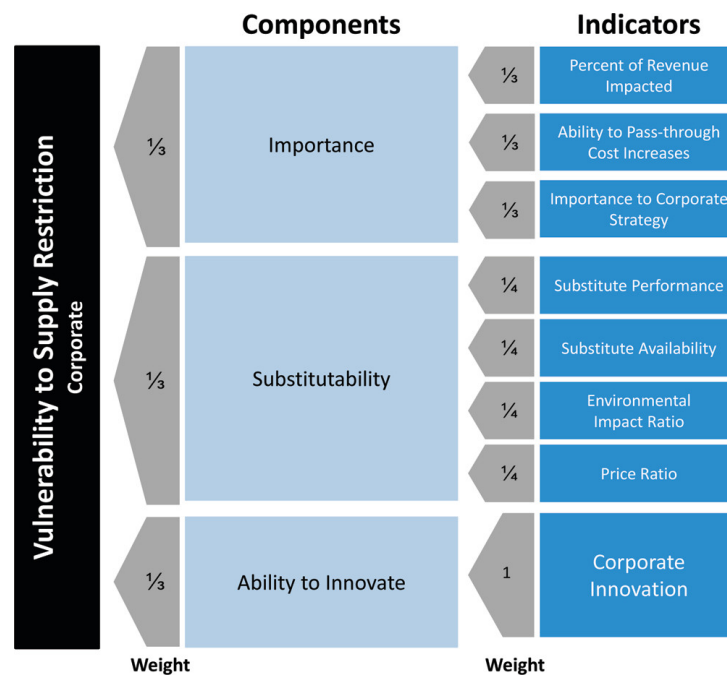
Alarmists have predicted mineral resource crises prematurely since the early 1970s (Meadows et al., 2013), but natural limits have not been reached so far. One of the main arguments against this bounding depletion is that shortages are signalled by rising prices, which automatically call forth investments in technological alternatives (Ayres, 2002). The analyses of USGS data show that the known reserves for key materials such as cobalt, lithium, and nickel increased between 2013 and 2022, indicating the supply elasticity (Cohen, 2023). Furthermore, depletion indexes often rely on static variables (Van Oers & Guinée, 2016), while real-world factors can significantly alter outcomes. For example, during the 2010 neodymium crisis, production increased faster than typical mine development timelines suggest, facilitated by the increased viability of co-production at existing sites (Sprecher et al., 2017). In conclusion, while CRM shortages due to demand increases are an important long-term risk, due to the time-scope adopted in this thesis it will be considered out of scope.

Graedel et al. (2012) name the supply potential, geopolitical factors, and intensity of competition as crucial characteristics in assessing material-related risks for corporations. However, there seem to be no papers explicitly listing all risks relevant for companies in the Netherlands. This is mentioned in the research gap and this axis and its components will be further studied in SQ1: *What are the main risks associated with companies' dependence on CRM?*

Secondary axis of criticality assessment: impact

For the second axis, the overall theme is the impact or vulnerability that can arise from the supply risk. However, there is little consensus about the best approach to determine this (Dewulf et al., 2016). In the assessment of the European Union, this is calculated by examining the possible economic impact on the region (Commission, 2024). Other approaches, e.g. for company-specific analysis, take the value of all goods sold containing the critical material. Graedel et al. (2012) composed a methodology for corporations to assess the secondary axis, which they named 'vulnerability to supply restrictions'. The components can be seen in figure 2.1.

Graedel et al. (2012) mention that the evaluation of metal substitutability is a complex task, involving multiple steps such as identifying key end uses, quantifying usage shares, determining substitutes for each application, and evaluating substitute properties, where each step can be a research project in itself.



**Figure 2.1:** Components of corporate vulnerability to supply restrictions (Graedel et al., 2012).

#### Company specific criticality assessments

Griffin et al. (2019) constructed a framework for a firm-level criticality assessment. They note that the existing literature disproportionately addresses criticality risk on an aggregate basis (e.g. industry, national, and global), with few studies considering the impacts of material criticality at the individual firm level. They created a new framework that focusses on individual firms, but only for companies that produce or sell manufactured goods. In addition, the difficulty of undertaking a criticality assessment from a company perspective is highlighted by the fact that due to the amount of work, the study continues with a case study of only one specific material, applied in one product, measured on one risk variable.

#### 2.2.3. The European Context: CRMA and EU assessments

##### Critical Raw Material Act (CRMA)

The CRMA is legal framework, aimed at securing a sustainable access to CRMs in the European Union. It entered into force in May 2024 Office of the European Union (2024). It sets benchmarks for recycling, use of recycled materials and for improving monitoring and risk mitigation. The framework includes a list of 34 Critical Raw Materials (CRMs). A subset of CRMs are the Strategic Raw Materials (SRMs), which consist of 14 materials of high strategic importance for key sectors: IT, the energy transition, defense, and aerospace. For all these strategic materials, there is a potentially significant gap between global supply and projected demand Commission (2023a).

### 2.3. Corporate preparedness, awareness and sense of urgency

#### 2.3.1. The concept of risk awareness

Awareness of a risk is the combination of the recognition of a risk, understanding the implications, and connecting the issue to oneself or the organisation (Trevethan, 2017). In his foundational work on risk perception, Slovic (1987) argues that awareness of a risk can trigger an emotional response, which in turn increases the sense of urgency to address that risk. In their book on how problems are addressed in the government, Kingdon and Stano (1984) stress the importance of a situation being recognized as a problem to be included in the agenda. Before the necessary urgency can be felt or action considered to address complex risks, like CRM supply issues, the risks must first be recognized and defined as significant problems within the management.

Ayres (2002) found that one of the main reasons companies do not take advantage of opportunities that would be in their own economic interests is the lack of critical information and knowledge at the decision-making level. A reason for this mentioned by Whalen and Peck (2014) is that many companies

view CRM as regular commodities and track their prices rather than building risk mitigation strategies. Previous research highlighted the apparent lack of awareness by industry of the potential risks posed to manufacturers at the product level from CRM supply (Lapko et al., 2016).

### 2.3.2. Disruption preparedness

Mitroff and Alpaslan (2003) found that only a small fraction (5-25%) of Fortune 500 companies were adequately prepared for crises, which shows that general preparedness for supply chain disruptions was low in 2003. They distinguish between 'crisis prone' companies, which react mainly to past events and, as a result, can only handle calamities they've already suffered, and 'crisis prepared' companies, which proactively develop plans for a wider range of potential emergencies (Mitroff & Alpaslan, 2003).

Research indicates varying levels of corporate awareness regarding CRM supply risks. Studies that involved interviews and roundtables with company directors and academics have explored the perception and quantification of these risks at the firm level (Slowinski et al., 2013a) (Peck, 2016) (Schoolderman, 2011). Slowinski et al. (2013a) reference a risk assessment approach by General Electric, which rated material risk based on factors such as the percentage of world supply used, affected revenue, substitutability and the ability to pass costs.

### 2.3.3. Knowledge-action gap

A barrier to corporate action on long-term threats is the 'knowledge-action gap', where knowing about risks is not enough to initiate action, especially if these risks are long-term or abstract (Kollmuss & Agyeman, 2002), which Fredberg and Pregmark (2022) states contributes to organisational inertia. Polman and Winston (2021) argues that companies prioritise short-term performance over long-term risks, called organisational short-termism, which Lavery (2004) describes as the tendency of companies to prioritise short-term financial and operational performance over long-term strategic preparedness. Spence et al. (2012) found that long-term and complex risks can suffer from 'psychological distance', a phenomenon that makes them feel less tangible and urgent than daily operational and financial pressures, reducing cognitive weight and urgency in addressing these issues. Van Lange and Huckelba (2021) state that reducing psychological distance is essential in order to combat societal challenges such as climate change, based on the idea that climate change is a social dilemma, where individuals have to choose between short-term individual gain or cooperative behaviour on the long term. Fredberg and Pregmark (2022) found that if there is a perceived threat nearby, this creates the motivation needed to move away from the current state and toward a new state. Although psychological distance is often mentioned in traditional sustainability transition studies, regarding emissions and climate change, it has not previously been applied in CRM studies.

These theoretical perspectives indicate that long-term risks, such as CRM supply shortages due to growing demand, are likely to receive insufficient attention in day-to-day management.

## 2.4. Change management

The field of organisational change management describes the processes which are employed to renew an organisation's direction, structure, or capabilities (By, 2005). While there is an ever-growing base of literature which emphasises the importance of change and while suggesting ways to approach it, little empirical evidence has been provided in support of the different theories and approaches suggested (Guimaraes & Armstrong, 1998). An important practical work in the field of change management is the influential 8-step change model by Kotter (1996a). The first step in this model describes the critical role of urgency in driving organisational change, which was later elaborated further by introduction of a book focussed on the 'sense of urgency' (Kotter, 2008). Establishing a sufficient sense of urgency is the essential first step to mobilize an organisation and overcome inertia towards needed transformations. Without a perceived need for change, individuals and organisations are unlikely to commit the resources and effort required for proactive risk mitigation.

### 2.4.1. CRM in Supply Chain Risk Management (SCRM)

An important concept in regards to this study is how change in CRM-usage in companies is achieved. There appears to be a gap in research on the specific management of CRM policy. Therefore, change management papers are studied on other topics to better understand the main concepts and theories in this field. A study by Giannakis and Papadopoulos (2016) approaches sustainability issues from a supply chain risk perspective. It concluded that the identification of sustainability-related supply chain risks,

the evaluation of their impact, and the development of risk management are critical for supply chain managers (Giannakis & Papadopoulos, 2016; Hofmann et al., 2014). Focussing on CRM from a supply chain risk perspective offers a more pragmatic approach to the topic, as periodic risk assessments are standardised in any company (Giannakis & Papadopoulos, 2016). Supply chain risk management (SCRM) is one of the main research topics in the supply chain management literature (Giannakis & Papadopoulos, 2016; Tang, 2006).

SCRM is a systematic approach, consisting of the following five sequential stages: risk identification, assessment, analysis, treatment, and monitoring (Giannakis & Papadopoulos, 2016). Through these stages vulnerabilities and threats throughout the supply chain are identified, after which mitigation strategies are developed to reduce the likelihood or impact of those threats (Ho et al., 2015). A comprehensive study by Rao and Goldsby (2009) divides supply chain risk factors in the following five categories; environmental factors, industry factors, organisational factors, problem-specific factors, and decision-maker related factors. For CRM supply, the most fitting variable among these is part of the industry factors; the input market uncertainty. This refers to the uncertainty in acquisition of adequate quantities and qualities of inputs into the production process. However, no empirical data was found about companies having integrated CRM in their SCRM strategy. Currently, Kim and Davis (2016) found that companies often have little knowledge about the critical materials in their supply chain. Among the 1300 companies studied, they found that only 1% could state with certainty that their supply chain did not contain materials from the DRC, while 80% could not determine the country of origin of materials that were at risk of being conflict minerals.

Other studies argue against a SCRM approach. Manuj et al. (2014) found that existing SCRM management is often ineffective, with a study conducted by Deloitte concluding that 45% of 600 surveyed supply chain and C-level executives considered their supply chain risk management programs to be only "somewhat effective" or "not effective at all." Only 33% reported using risk management strategies that proactively and strategically addressed supply chain risks in response to their specific operating conditions. Also, treating CRM as regular commodities might work disadvantageously. It is argued that traditional supply chain management practices may be ineffective in mitigating CM risk as standard free market conditions may not apply due to geopolitical factors such as quotas or sanctions Gardner and Colwill (2018).

## 2.5. Identified literature gap

The review highlights extensive research on supply risks for CRM, both in the scientific and gray literature. The topic is studied from a national (Bastein & Rietveld, 2015; Patrahau et al., 2023) and European perspective (Blot, 2024; Righetti & Rizos, 2024). In recent years, many studies have been published that assess criticality (Commission, 2023b; U.S. Geological Survey, 2023) or study the assessment of criticality (Achzet & Helbig, 2013; Schrijvers et al., 2020). Apart from that, some research focus on sectors or industries, most often the energy sector (Arup, 2025; Gervais et al., 2025; Helbig et al., 2016; International Energy Agency, 2025; Montana et al., 2024), IT (Althaf & Babbitt, 2021; de Pooter et al., 2022) and defence sector (Girardi et al., 2023; of Defense, 2018; Patrahau & Girardi, 2024).

Specific effects from CRM usage have been studied. For example, the causes and effects of price volatility (Vogtländer et al., 2019). Other studies focus on the more general effects of supply chain disruptions (Alonso et al., 2007; Olivares-Aguila & ElMaraghy, 2021; Wu et al., 2007) and the effect of geopolitics (Bednarski et al., 2025; IRENA, 2023). However, in scientific research, an overview of CRM supply risks from a company perspective seems incomplete.

The field of corporate awareness of Critical Raw Material (CRM) risks remains critically understudied. Although some early grey literature measured CRM risk awareness among companies in the Netherlands, this work is quite dated as it is more than 14 years old (Schoolderman, 2011). An academic contribution on topic is found, which is the dissertation by Peck (2016) which specifically addresses CRM use and risk perception by companies. A key finding from that research was that while companies were aware of CRM in general, they did not expect any reduction in use in the coming years. In addition, companies preferred passive mitigation strategies, such as stockpiling or long-term contracts, over proactive changes to product design. This preference for reactive measures suggests that even when there is some awareness, it may not translate into a high sense of urgency for fundamental strategic change.

Regarding studies researching how CRM risk awareness can be increased, only a serious game design has been found that aims to improve the awareness of CRM risk among participants by Whalen and

Peck (2014), in which it is stated that minimal tools had been found before that study to create CRM awareness. No studies on increasing awareness of CRM risk in a business context appear to have been published after that.

In change management, the most influential study by Kotter (1996a) states that internal change projects without a perceived sense of urgency are likely to fail. There are several strategies and mitigation actions described that companies can implement if they want to reduce CRM usage (Gaustad et al., 2018; Lapko et al., 2016; Peck, 2016). How the change process towards a more sustainable CRM usage in companies can best be initiated seems never to have been studied. There appears to be a gap in research on how companies can best initiate these measures.

By integrating the existing scientific and gray literature, this study aims to create an overview of CRM supply risks to fill a theoretical gap on which risks are relevant to companies in the Netherlands in SQ1 5. By integrating existing theories on raising awareness by Whalen and Peck (2014) and a sense of urgency by Kotter (1996a), Chapter 6 and 7 will describe how a tool will be created with the aim of raising awareness, built on the previous efforts by Whalen and Peck (2014). Thereafter, the tool will be employed in practice. Results from qualitative and quantitative measurements will add to existing knowledge about the tools available to increase decision makers' sense of urgency for CRM supply risks, which will in turn answer the main research question of this thesis.



## Theoretical framework

This chapter outlines the theoretical framework that guides this research. It presents the core concepts and theories that guide the research and support the study's aim.

For analysis of the data, each concept has been further divided in sub-concepts in Chapter 4.4. The table with the final sub-concepts can be found in the Appendix A.

### 3.1. Key constructs

#### 3.1.1. Risk awareness

The concept of 'Awareness' in this study refers to the understanding and recognition of the participants of critical raw materials (CRMs), the associated supply risks, and the implications for their organisation and sustainability. Increasing awareness is one of the main objectives of scenario planning interventions (Cairns & Wright, 2017), as a foundational step toward creating urgency and strategic action.

There is no formal definition of 'Risk awareness'. However, the concept is introduced by previous research. Jen (2012) state that risk awareness is the raising of understanding within the population of what risks exist, their potential impacts, and how they are managed. Awareness includes the recognition of risks, understanding the implications, and connecting the issue to oneself or the organisation. Awareness of an issue can be compared with having knowledge of its existence and its relevance (Trevethan, 2017).

In this study, risk awareness is taken as the result of a 'CRM risk understanding' and the 'applicability to organisation'. Risk awareness has been argued to be a fundamental pillar of an appropriate risk culture (Braumann et al., 2020), in which a risk culture refers to the abilities that an organisation or group has to assess and mitigate risks.

#### CRM risk understanding

Understanding the topic of critical raw materials, knowledge of risks and factors that cause risks is considered indispensable for companies who want to implement a strategy to mitigate these risks (Griffin et al., 2019).

#### Applicability to organisation

'Applicability to organisation' covers the psychological connection someone makes between an external risk and the implications to their organisation. In his influential study on risk, Slovic (1987) states that risk is strongly influenced by perception. This perception is determined by a wide range of characteristics, such as the perceived impact and controllability of the risk factor. Understanding the impact of CRM supply disruptions, material price volatility, or other future uncertainties that may have on the organisation is therefore an important factor in how these uncertainties are perceived.

#### 3.1.2. Sense of urgency

'Sense of Urgency' is defined in this research as the perceived motivation within individuals or an organisation to address identified (CRM supply) risks. As articulated by Kotter (1996a), a sense of urgency is essential to initiate and sustain any significant organisational change. Without a perceived need for change, individuals and organisations are unlikely to commit the resources and effort required for

proactive risk mitigation. This concept is central to the thesis, as the scenario planning intervention is hypothesised to directly influence this sense of urgency.

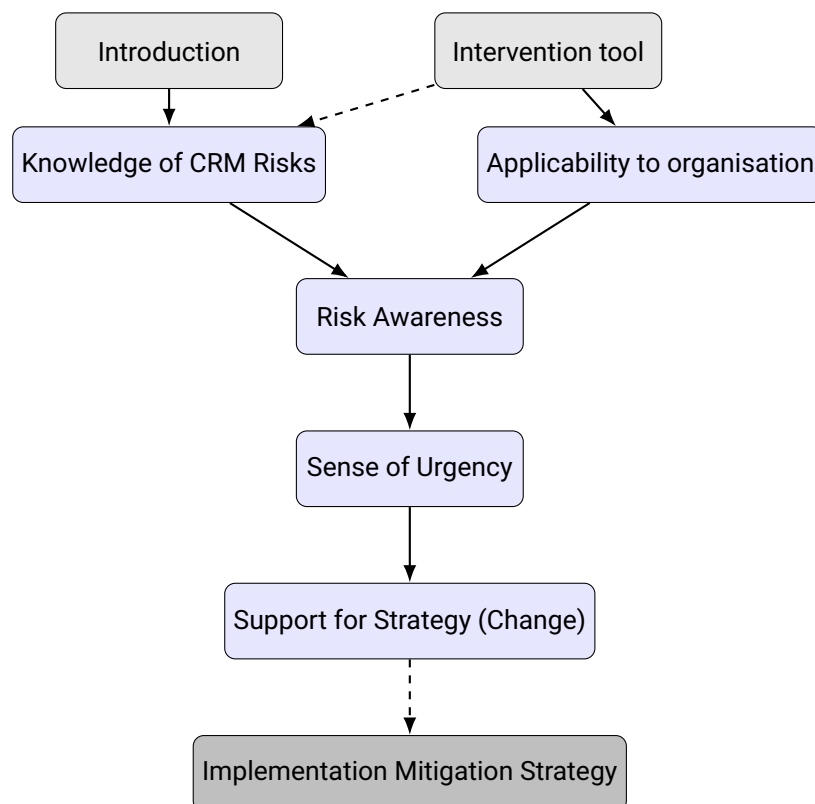
The theoretical foundation of a "sense of urgency" is built on the concepts of risk perception, which explain how individuals perceive and react to potential threats. Theories on psychological distance, such as Spence et al. (2012) are particularly relevant, suggesting that risks perceived as distant in time or space are often given less cognitive weight and urgency than immediate concerns. This is related to aspects of organisational behaviour, specifically theories addressing organisational short-termism such as Lavery (2004), which highlight the tendency of companies to prioritise short-term financial and operational performance over long-term strategic preparation. These theoretical perspectives indicate that abstract long-term risks, such as certain CRM supply disruptions, are likely to receive insufficient attention in day-to-day management.

### 3.1.3. Support for organisational strategy

A sense of urgency felt among employees does not automatically translate to a reduced dependency on CRM within a company; this requires mitigation strategies to be implemented. Within the scope, it cannot be researched whether an increased sense of urgency among participants will translate to implemented strategy. This limits this concept to 'support for organisational strategy', which can be measured during this research. This requirement of support for the implementation of mitigation strategies is mentioned in CRM supply risk literature. For example, Griffin et al. (2019) states that the integration of mitigation strategies requires the participation of internal stakeholders throughout the organisation, starting with management.

## 3.2. Conceptual model

Based on this theoretical framework, this study is built on the following interconnected propositions regarding CRM supply risks and the application of the intervention. These are visually displayed in Figure 3.1.



**Figure 3.1:** Conceptual framework illustrating the causal pathway from intervention to strategic action on CRM risks

### 3.2.1. Intervention tool -> Applicability to organisation

The core proposition is that participation in a communication tool can make potential risks, even those that are abstract or long-term, feel more tangible and real to decision makers. As explored in Chapter 6, SP theory argues that by constructing and exploring multiple plausible future narratives, organisations can challenge ingrained assumptions, improve their understanding of environmental uncertainties, and improve strategic flexibility and resilience Cairns and Wright (2017), Dean (2019), Harries (2003), Ramírez and Selin (2014), and Schoemaker (1995).

CRM risks, particularly those related to long-term supply vulnerabilities and geopolitical factors, are often perceived as too abstract and psychologically distant for decision makers to adequately consider in daily management and strategic prioritisation. By actively participating in the process of conceptualizing and exploring these risks through structured narratives and discussions inherent in scenario planning, participants can better understand and consider the potential impacts.

### 3.2.2. Risk knowledge + Applicability to organisation -> Risk awareness

As mentioned above, Jen (2012) has described risk awareness as understanding of what risks exist and their potential impacts on the organisation. The causal connection between risk knowledge and risk awareness has previously been demonstrated in the field of natural hazards. Scolobig et al. (2012) showed that increasing knowledge about risks was essential to increase awareness of risks. The improvement of the residents' knowledge about their environment and residual risk appeared to be crucial to increasing risk awareness.

### 3.2.3. Risk awareness -> Sense of urgency

In his foundational work on risk perception, Slovic (1987) argues that awareness of a risk can trigger an emotional response, which in turn increases the sense of urgency to address that risk. In his book on how problems are addressed in the government, Kingdon and Stano (1984) stresses the importance of a situation being recognized as a problem to be included in the agenda. Before the necessary urgency can be felt or action considered to address complex risks, like CRM supply issues, the risks must first be recognized and defined as significant problems within the management.

A comparison can be drawn from flood awareness to supply risk awareness, as Scolobig et al. (2012) stated that if people underestimate the intensity of a flood, they will not take the necessary cautionary actions to protect themselves, showing a causal link from awareness of a risk to the sense of urgency felt. In terms of CRM, if companies underestimate the effect future disruptions may have, they will not feel a need allocate resources now towards mitigating these risks.

### 3.2.4. Sense of urgency -> Support for organisational strategy

Many studies highlight the importance of urgency as driver for change or new strategies. This is one of the key concepts from Kotter (1996a) change model, which describes how a sense of urgency is the basis for the next steps to create change in an organisation. In the field of supply chain management, the importance of urgency to prompt the implementation of sustainable initiatives has been mentioned in previous studies (Guan et al., 2025). In their study into Green Supply Chain Practises (GSCP) Guan et al. (2025) stress the importance of prioritizing green practices over the status quo. In order to get this prioritization, they state urgency is necessary. This finding shows the causal link between a sense of urgency and the support for new strategy.

### 3.2.5. Support for organisational strategy -> Mitigation strategies

The causal effect of change following a sense of urgency seems understudied. Scolobig et al. (2012) state that residents' level of risk awareness is positively related to their willingness to adopt precautionary measures, in their case to flood risk. However, they stress that that awareness of risk is not automatically translated into actual behaviour. Within the scope of this thesis, it is not feasible to research whether an increased support for strategy will lead to strategies being enforced within the organisation. It is strongly recommended to investigate this link in future research, as described in the limitations, Chapter 10.

# 4

## Methodology

This research is based on a pragmatist philosophy. Through initial communication with the commissioner, it became clear that in the field of CRMs it is not a lack of scientific proof which hinders the implementation of mitigation strategies in companies, but rather the practical application of this knowledge, and awareness at companies of this knowledge. Using research to find ways to change this fits with the basic principles of pragmatism, which are (1) an emphasis on actionable knowledge, (2) recognition of the interconnectedness between experience, knowing and acting, and (3) a view of inquiry as an experiential process (Kelly & Cordeiro, 2020). Through implementation, the effectiveness of engagement with the tool on participants' awareness of CRM supply risks and their sense of urgency towards mitigating these risks will be assessed.

This research adheres to an Action Research (AR) approach. AR generally has a dual purpose; to contribute both to the practical concerns of society or an organisation, and to the goals of science (Näslund et al., 2010). Previous studies by Bradbury et al. (2019), Fazey et al. (2018), and M. A. Thomas (2010) state that AR is very useful in the field of sustainability and exploring transformative processes that actively seek to question the way we produce and use knowledge in learning, education and research. Action research can be referred to as research focussing on collaborative learning processes with experiments which provoke future learning (Bradbury et al., 2019). This is twofold, research can inform practice, but practice is also used to inform research (Näslund et al., 2010). The combination of lack of previous studies in the field of CRM awareness and sense of urgency, and the aim of finding a tool which is feasible in practice, substantiate the choice for this research method.

For this research, a multi-stage iterative AR was designed, as visually represented in the research framework, Figure 4.1. This chapter outlines the research design and several methodological components employed to address the research question and its sub-questions.

### 4.1. Research design and data collection

The research is structured in four distinct phases, directly aligning with the sub-questions as outlined in Chapter 1.1. This chapter will discuss the methodology for each of these questions, including the data sources and tools used and analysis method(s) applied.

#### 4.1.1. SQ1: Exploration of CRM supply risk

This initial phase focusses on establishing a foundational understanding of short-term CRM supply risks within the context of geopolitical factors, relevant to Dutch companies.

##### Sources

A systematic approach was taken to gather information from diverse sources:

- **Academic databases:** Comprehensive searches were conducted in academic databases including Google Scholar and Scopus. Keyword combinations such as "critical raw material," "Critical mineral" "supply chain risk," "supply risk," "disruption," "material scarcity," "geopolitical supply risk," were used. Inclusion criteria for academic sources focused on peer-reviewed articles, reports, and conference papers published within the last 15 years to ensure relevance to contemporary supply

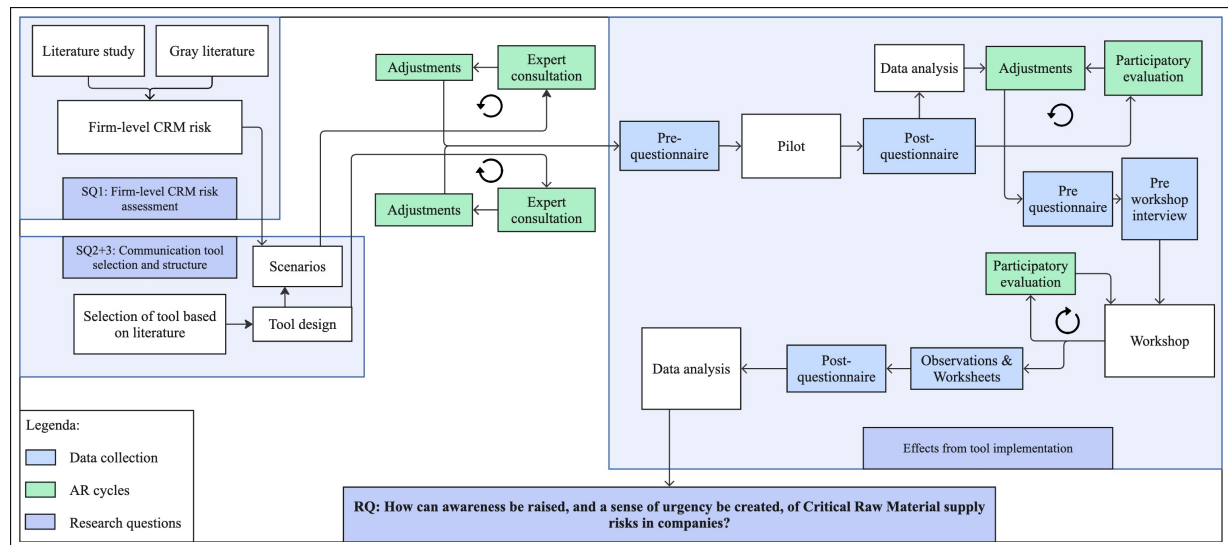


Figure 4.1: Visual representation of action research framework applied in this study

chain dynamics. References in the articles were followed up which allowed for more sources to examine. This is consistent with the methodology provided for literature study in Creswell and Creswell (2017).

- **Gray literature** The gray literature was selected according to the following criteria; report published in the last 3 years; renown source; relevance to Netherlands, EU or international community; Critical Materials or similar term in the title or implicitly mentioned. This resulted in the following reports: from authoritative governmental bodies (Commission, 2023a; Office of the European Union, 2024)), publications from international organisations (International Energy Agency, 2025; IRENA, 2023; OECD, 2024) and think tanks (de Pooter et al., 2022; HCSS, 2024; IISS, 2025) and a advisory firm (Arup, 2025).

#### Digital assistance tools

Supplementary digital tools, including AI-powered platforms like Elicit and Gemini, were used to enhance the search process. These tools assisted in identifying potentially relevant papers and synthesise information from hundreds of papers. All findings generated through these tools were critically cross-referenced and verified through traditional database searches and full-text reviews to ensure accuracy and relevance.

#### Method

The primary method employed in this phase is data collection through extensive literature review and desk research. By comparing academic literature with gray literature, this chapter aims to identify and address potential gaps in academic theorizing or empirical coverage of specific CRM risks, while also providing a richer contextual understanding informed by real-world practitioner reports and policy documents.

The use of literature review and desk research to analyze CRM supply disruptions is supported by prior studies by Althaf and Babbitt (2021) and Achzet and Helbig (2013), which focus on supply risk evaluations and criticality assessments, respectively.

For the literature, a few comprehensive studies listing disruption risks in supply chains were sought. Information of these sources was listed, after a saturation point was reached where no new disruption categories were found in additional sources. This is similar to the approach used by Lapko et al. (2016), which listed several types of supply risks, and Althaf and Babbitt (2021), which focused on quantified metrics.

The methodological approach involves a further exploration of CRM supply risks by expanding on academic literature through a inclusion of insights from gray literature. This approach is supported by research by Adams et al. (2017), who argue that incorporating gray literature can be used to increase the relevance and impact of management and organisation studies. As the goal of this thesis is to increase awareness for the relevance of CRM risks in management and corporate strategy, integrating insights



from gray literature is beneficial to improve the relevance of the chapter's findings for companies. Adams et al. (2017) note that gray literature is particularly valuable for "incorporating relevant contemporary material in dynamic and applied topic areas". This makes the method highly relevant in the field of CRM where global trade relations are quickly evolving. Gray literature assessed includes non-academic sources such as papers from renowned think tanks and government organisations. However, selection criteria have been included to ensure credibility and relevance. Sources have to be: I. published by governments, reputable organisations or think tanks, II. published in the last 3 years, III. be retrievable online. The resources used for this comparison are listed in appendix B. Using gray literature for better understanding supply risks is appropriate as it has been used in previous research into criticality and supply risks by Ioannidou et al. (2019).

The synthesis of information from these sources allowed for the identification and characterization of key short-term CRM supply risks relevant for companies.

#### 4.1.2. SQ2 and SQ3: Selection and construction of a communication tool

Building upon the risks identified in SQ1, tools which theoretically can increase awareness and a sense of urgency regarding supply chain risks are studied. Various tools will be explored through desk research, after which the most appropriate tool for this thesis will be selected.

The selected tool will be further explored to choose the most suited method and approach. The composition of the tool, adjusting it to the practical implementation within this research. This process is described in SQ2, Chapter 6. Chapter 7 describes the constructed tool and provides guidelines on the implementation.

#### Tools & sources

- **Desk research:** A focused literature review was conducted to explore theoretical concepts related to risk perception (Harries, 2003; Spence et al., 2012), organisational decision-making under uncertainty (Knight, 1921; Mitroff & Alpaslan, 2003), communication strategies for raising awareness, and the literature on creating a sense of urgency in organisational change processes (Kollmuss & Agyeman, 2002; Kotter, 1996b). Initial expert consultations (as described below) and a preliminary literature review indicated that scenario planning is considered a useful tool to address uncertainty and create awareness, leading to a deeper investigation into its theoretical foundation and practical application. The varying terminology in the literature, such as scenario development, scenario planning, and scenario thinking (Varum & Melo, 2010), was taken into account in search strategies.
- **Case study research:** Analysis of documented cases in which organisations have successfully used scenario planning, particularly in contexts involving uncertainty and strategic foresight. Three documented cases were selected based on their availability in the literature and relevance to the use of SP to manage uncertainty or increase awareness, for example, the Shell case study (Cornelius et al., 2005), British Airways (Moyer, 1996), and the local government of Blekinge (Thomson et al., 2020). The analysis focused on understanding their motivations, methods, process, and perceived outcomes related to addressing uncertainty.
- **Expert consultation:** Off-the-record interviews were conducted with experts in the field of supply chain management and workshop facilitation. The experts were selected based on their knowledge about the role of CRMs in company risk assessments or their experience facilitating workshops related to risk management or strategic foresight. For composition of the scenarios, the uncertainty factors and possible scenarios were discussed with an expert from the Clingendael Institute and several consultants from Copper8. These interviews and consultations served to gather practical insights into the challenges of creating management urgency around abstract or long-term risks and to explore practical techniques used in industry, complementing the academic literature.

The findings of this phase informed the design of the tool. The construction of the tool will be further elaborated in SQ2, Chapter 6.

## 4.2. Workshop intervention

To answer the third sub-question of this thesis: *What effects can be observed from the intervention with the selected communication tool?*, it is important to have a clear description of the tool implemented. This is provided in Chapter 7. Building upon the understanding of CRM risks (SQ1) and the potential of scenario planning to create urgency (SQ2), this chapter details the design and implementation of a participatory

scenario planning workshop and the subsequent assessment of its impact on participants' perceived urgency regarding CRM supply risks. The methodology used aligns with an action research approach, evaluating an intervention within a real-world context. The evaluation methodology is described in the following section.

Figure 4.1 illustrates the action research methodology employed to answer SQ3: *What effects can be observed by implementation of the chosen tool?* This phase was built on the findings of SQ1 (*identification of CRM supply risks*) and SQ2 (*selection of a risk communication tool*). The AR involved iterative cycles of designing, implementing (acting), observing (collecting data), and reflecting on the workshop. The author's role was that of an active participant-observer and facilitator, consistent with action research principles.

#### 4.2.1. Research spiral

In AR, the participation of the subjects studied in the cyclic research process will increase authenticity and trustworthiness, because part of the analysis is conducted collaboratively (Näslund et al., 2010). Including consultants in the formation of the SP workshop they might use in practice is therefore deemed appropriate in the creation of this tool. Including industry participants in the workshop evaluation process also aligns with this AR approach.

The process began with the development of the workshop concept and materials, incorporating literature and expert feedback (Phase 1). This is in line with the characteristic of AR where research is used to inform practice.

This was followed by an internal pilot workshop (Phase 2: Cycle A), involving planning and conducting the workshop, collecting pre- and post-evaluation data from participants, and reflecting on the outcomes to refine the tool. Participants are employees from a sustainability consultancy, with various backgrounds. Before and after the workshop, they filled in a questionnaire which assessed their previous knowledge and experience on CRM supply risks, and aimed to understand the sense of urgency of the risks.

To participate in the workshop, the participants were provided with a proxy company and professional roles. This approach was chosen because the consultancy itself does not trade in any products or components, making the effects on their own company likely too insignificant.

The proxy company description was generated with AI (Gemini 2.5) with the prompt '*Kan je een profiel maken van een installatietechniek bedrijf (met een korte omschrijving wat ze doen, welke materialen ze in hun waardeketen hebben en hoe ze aan deze materialen komen) een rollenspel scenario planning workshop over Critical Raw Material supply risks in de toekomst. Bedenk hierbij 6 verschillende functies uit verschillende takken van het bedrijf.*' (translated: *"Can you create a profile of an installation technology company (with a short description of what they do, which materials they have in their value chain, and how they acquire these materials) for a role-playing scenario planning workshop about future Critical Raw Material supply risks. Include 6 different roles from various branches of the company."*). The proxy company description is provided in Appendix O.

Observation was selected as one method of data collection because it is important for the researcher to have a better understanding of what happens during the workshop. In addition to formal written feedback, participants also gave feedback and suggestions during and after the workshops. The main change after the pilot workshop was the implementation of working sheets to better structure the SP process. Other adjustments to the evaluation process and the presentation of the workshop were also included. As this is an outcome of the AR research, this is described in Results, Chapter 8.2.2.

The refined communication tool was then implemented in an external company setting. To assess the effect of a scenario planning workshop on the sense of urgency concerning CRM supply risks, a mixed-method approach was adopted, with data collected through pre- and post-evaluations, semi-structured interviews, observations, and analysis of the produced material to comprehensively assess its effects on participants' awareness and sense of urgency regarding CRM supply risks, thus directly addressing SQ3.

#### 4.2.2. Workshop design and implementation

A 3-hour scenario planning workshop was developed based on the insights gained from the literature review and expert consultations in Phases 1 and 2. The content of the workshop, including the specific CRM risks discussed and the future scenarios explored, was directly informed by the findings of Phase 1. The structure and facilitation techniques applied were grounded in the principles and practices of

scenario planning as examined in Phase 2. The workshop design, including the agenda and specific activities, is provided in Chapter 7. The workshop required minimal materials, primarily consisting of large sheets for outlining scenarios (starting with a pre-drawn matrix based on key uncertainties), worksheets and a suitable space to accommodate group interaction. The slides used in the workshop are attached as additional material.

At the end of the workshop, a group discussion was followed on the perceived experience and effectiveness of the workshop itself. This is recommended as a form of focus group, reducing the time and planning required from the participants.

#### 4.2.3. Facilitating role

Consistent with AR principles, the author's role is that of a participant-observer and facilitator. This dual role allows for direct engagement in the co-creation of the workshop and provides rich observational data. The author acknowledges that this positionality could introduce bias; this was mitigated by adhering to a structured facilitation guide (as outlined in SQ3, Chapter 7) triangulating data from multiple sources (questionnaires, interviews, and worksheets), and creating space for participant-led discussions.

#### 4.2.4. Participants

Participants were recruited from the Copper8 network. An invitation was sent to companies within this network, outlining the workshop's format, time commitment, and focus on Critical Raw Materials (CRMs) and future scenarios. In addition to that, companies that likely have a physical supply chain with CRMs, such as IT or energy companies, were directly approached.

The company participating in the workshop operates in the installation sector. Although the company does not manufacture any products themselves, it handles large volumes of CRM containing products through projects, mostly IT and climate technology. The company is categorised as a large company, employing more than 250 employees (Kamer van Koophandel, 2024). To protect privacy, the identity of the company and the individual participants will remain anonymous.

### 4.3. Data collection and analysis process

The questions in the pre-workshop questionnaire were designed to measure the sub-concepts as described in the theoretical framework, Chapter 3. These definitions informed the interview guides and guided both data collection and coding. This improved data consistency and ensured that conclusions were based on the academic literature rather than on subjective interpretations of constructs.

#### 4.3.1. Data collection instruments: interviews, questionnaires and worksheets

To assess the impact of the workshop, data were collected through a combination of pre- and post-workshop questionnaires and semi-structured interviews. Focussing awareness and avoiding questions regarding the specific contents of products avoids confidentiality and intellectual property challenges. As mentioned in Peck (2016), knowledge about the exact composition of parts is of high value. Fear of theft or accidental sharing of this information is a big obstacle for scientists in the field of CRM that focus on companies.

Although the workshop is primarily designed as an intervention tool to increase awareness and urgency around CRM supply risks, the discussion during the workshop and the post-workshop evaluation provides insights comparable to those obtained through a focus group. The purpose of focus groups is to gather the views of the participants on a topic (Morgan, 1996). In this case, the dialogue of participants following the content of the workshop served a similar function, offering valuable qualitative data on perceived relevance and urgency. Although not a focus group in the strict sense, this format has been accepted in similar intervention-based qualitative studies (Guest et al., 2017).

Data collection instruments were designed to capture changes in participant awareness, risk perception, sense of urgency, and strategic thinking related to CRM supply risks. These concepts are operationalised and elaborated in the Appendix A. Questions were developed based on these concepts and the established frameworks for assessing risk awareness in scenario planning Cairns and Wright (2017), and the study from Peck (2016) specifically addressing CRM risk awareness. A semi-structured interview approach was chosen to provide more depth to the responses to the questionnaire that needed further elaboration. The worksheets provided to participants during the workshops provide data on the level of strategy thinking of participants.

Data collected in this phase was done using different methods. This included:

- **Transcripts:** Audio recordings and subsequent transcripts of all pre-workshop interviews.
- **Questionnaires:** Results from pre- and post workshop questionnaires with labelled results per theme.
- **Field notes:** Field notes taken by the researcher/observer during the workshop, documenting participant interactions, key discussions, and non-verbal cues related to engagement and reactions.
- **Workshop material:** Any materials generated by participants during the workshop (e.g. notes on post-its, drawings on flip charts related to scenarios or strategies).
- **Expert interview:** An expert interview serves as the primary data collection method, to bridge the gaps where the research on the desk does not cover the scope of this research or to validate the findings of the desk. In this case, it was used to validate the scenarios used in the workshop.

#### 4.3.2. Pre-Workshop Questionnaire

Prior to the workshop and the interview, participants had to fill out an online questionnaire. The purpose of this questionnaire was two-fold:

1. To assess familiarity with CRMs, the perception of related risks, the current sense of urgency, and existing policies within the participants' organisations for pre- and post-workshop quantitative comparison.
2. The information collected was used to structure the personal interviews and align the content and focus of the first part of the workshop with the level of knowledge of the participants.

The questionnaire, as can be found in the Appendix C, consisted of several sections designed to assess the core concepts of the research. Summarised, these sections include:

- **General Information:** Basic details about the participant and their organisation.
- **Familiarity with CRM:** Measures the level of familiarity with the term CRM and its presence in the company's value chain.
- **Risk probability:** Asks about the estimated probability of CRM supply problems in the short, medium, and long term.
- **Urgency of risks:** Identifies which specific risks related to CRM are considered urgent.
- **Comparison with other risks:** Puts CRM risks into perspective relative to other strategic business risks.
- **Policy within the organisation:** Investigates the existence of the current CRM strategy.
- **Vision on CRM use reduction:** Gauges attitudes towards CRM reduction strategies.
- **Personal role:** Enquires about the participant's influence and relative knowledge level within their own organisation.

The questions consisted mainly of closed-ended questions with multiple choice options and Likert scales, facilitating the initial standardised collection of data (Dillman et al., 2014).

The questionnaire lays the groundwork for qualitative data collection through semi-structured interviews, where these concepts will be explored in greater depth. The responses of the questionnaire will be used to identify initial patterns and will serve as input for the interview topic guide, allowing a targeted and efficient interview structure. The combination of quantitative data from the questionnaire and qualitative data from interviews aims to provide a rich and nuanced understanding of the research questions (Creswell & Creswell, 2017), in line with the triangulation criteria for data collection highlighted in AR (Näslund et al., 2010).

## 4.4. Conceptualization

As the social constructs in this thesis, e.g. awareness and sense of urgency, are open to interpretation, theoretical concepts were conceptualised before data was collected. This is essential for adequately answering the research questions and systematically analysing the data. This conceptualisation process divides abstract concepts into definable (sub) definitions and characteristics (Creswell & Creswell, 2017). The basis of the conceptualisation was based on the relevant literature and the specific context

of CRM risk management. The conceptualisation process is iterative, allowing changes to be made based on observations and new information (Creswell & Creswell, 2017). During the interviews, the conceptualisation evolved as some concepts were added and others were removed due to redundancy. The central concepts in this thesis are; awareness of CRM Supply Risks, Sense of urgency (regarding CRM supply risks), organisational strategy & Communication tool acceptance. The final list of sub-concepts is shown in Appendix A.

#### 4.4.1. Awareness

As no (published) previous evaluation method was found for measuring CRM risk awareness in companies, the concepts have been chosen by combining different published researches. The dissertation of Peck (2016) on CRM usage and perception by companies informed the selection of most concepts. It should be noted that most of these concepts were not explicitly mentioned in the study but were mostly included in the qualitative research carried out to increase CRM awareness. The first few sub-concepts are based on this research. For example, 'Material Familiarity' (AW1) and 'Element-Product Link' (AW2) assess foundational knowledge about CRMs and their direct organisational relevance (AW4).

'Solution Awareness' (AW5) gauges knowledge of possible responses which can enhance supply chain resilience, such as strategic substitution, advanced recycling infrastructures, and product design. The paper by Whalen and Peck (2014) mentions the importance of including circularity aspects in the understanding of CRM (AW8). The work of Kolotzek et al. (2018) stresses the importance of including environmental and social sustainability in CRM risk understanding and assessment (AW6 & AW7). As Cairns and Wright (2017) states that the main goals of SP are understanding that the future will almost certainly be different from today, and the changes that will occur are unpredictable, it was chosen to include two more concepts; blackspot awareness (AW9) and observation of a changing environment (AW10).

#### 4.4.2. Sense of urgency

The 'sense of urgency' construct is operationalised through 5 distinct sub-concepts. In addition to the leading work of Kotter (1996a), recent studies on urgency in the context of sustainability and supply chain risks Guan et al. (2025) and Isaksson (2019) provide additional sub-concepts to measure the concept. 'Prioritising Risks' (SU1) assesses the relative importance participants assign to CRM risks compared to other risks. If urgency is felt, a risk is perceived as more pressing than others (Guan et al., 2025; Kotter, 1996a). 'Perceived Sense of Closeness' (SU2) captures the temporal dimension of urgency, as Guan et al. (2025) state that apart from the definition provided by Kotter (1996a), who states that urgency being of pressing importance, it can also be interpreted as demanding immediate attention. 'Pressure to Act' (SU3) reflects the perceived pressure of internal or external stakeholders, which according to Guan et al. (2025) is reflected by urgency. This is also mentioned by Kotter (2008), who states that feeling the need to respond to external threats is one of the key aspects of a sense of urgency. Beyond threat-driven urgency, 'Seeing Opportunities' (SU4) is also an aspect of urgency, as this has the potential to fuel a sense of urgency to act (Isaksson, 2019; Kotter, 2008). Finally, 'Willingness to Act Immediately' (SU5) serves as a direct indicator of behavioural intention, reflecting concrete plans or the explicit willingness to take short-term action, a critical outcome or urgency stressed by Kotter (1996a) in successful change efforts. This sub-concept can be seen as the necessary step for support of strategies.

#### 4.4.3. Organisational strategy

'Organisational strategy' measures the degree the company is already involved with CRM, and the expressed willingness of participants or the organisation to transform perceived risk and sense of urgency to strategy. Understanding this step is not covered in the research question. However, understanding the current position of the company and the tangible outcomes of the workshop is informative to place the perceived risk and the sense of urgency into context. In their study on how businesses could handle CRM risks, Kolotzek et al. (2018) state that the first step for any company is understanding what CRM are in their value chain. This is reflected by 'Material assessment (ST1)'. CRM-specific Strategies (ST2), like diversification, substitution, or enhanced recycling efforts, directly indicate a strategic response (Kolotzek et al., 2018; Peck, 2016). 'Prioritization of Materials' (ST3) is based on step 3 of the model of Kolotzek et al. (2018) that states that companies must focus their efforts on the most critical or vulnerable materials within their portfolio. The 'Proactive vs. Reactive Stance' (ST4) of an organisation is an important distinction in understanding the risk approach as described in the strategic management and crisis literature by Mitroff (2005). Finally, 'Comparison with Other Organisations' (ST5) was included



as organisations often benchmark their strategies and preparedness against peers or industry standards, which can influence their own strategic direction (Kolotzek et al., 2018).

#### 4.4.4. Acceptance of tool

A fourth category, acceptance, was added to assess the subjective opinion of the SP workshop. This category does not directly support the answer to the research question, but is important to answer whether the workshop would be adopted in a practical business context. One of the building theories on whether a new tool or technology is adapted is the Technology Acceptance Model (TAM) (Burgess & Worthington, 2022). This model argues that acceptance is based on two factors; the Perceived Usefulness (PU) and the Perceived Ease of Use (PEOU) (F. D. Davis, 1989). Studies on the specific application of the TAM to a risk awareness tool seem non-available. However, the use of the tool is appropriate here, as Alsofyani et al. (2012) showed that the TAM can be used to evaluate a workshop in the company.

### 4.5. Data analysis

Data from the pre- and post-workshop questionnaire will be analysed to identify themes in the concepts. Where applicable, these can be analysed quantitatively using Likert scales, and qualitatively general trends in participant responses will be analysed. The initial analysis of the pre-workshop questionnaire will help in identifying common themes and points of interest relevant for the subsequent interviews and the scenario planning workshop. Qualitative data from the interviews will be thematically analysed through coding. This is a general practice in AR (Näslund et al., 2010) and helps to distinguish recurring themes. A list of concepts had previously been conducted in the research, to form a framework for the questionnaire. During and after the interviews, an iterative process followed, refining, combining, or separating the codes. This is in line with the theoretical thematic approach, where it is aimed to link the answers to the pre-conceived themes in order to answer the research questions (Braun & Clarke, 2006). This method is consistent with established qualitative research practices for identifying patterns, connections, and recurring themes in interview data (Creswell & Creswell, 2017).

The transcripts of the pre- and post-workshop interviews were analysed using the same thematic analysis to identify recurring themes related to risk perception, urgency, understanding of CRMs, and the impact of the workshop. This allowed for triangulation of findings with the questionnaires and the elaboration of the answers provided there. As no post-workshop interviews were conducted, comparative analysis was limited to using the post-workshop focus group and individual questionnaire. The interviews are recorded and transcribed with Turboscribe, a special web tool for transcribing audio files. The transcriptions are carefully checked for errors and corrected.

**Workshop Data Analysis:** Field notes and participant-generated materials were analysed to provide context and support the interviews' findings, capture the dynamics and key results of the workshop discussions. The analysis aimed to synthesise insights from both qualitative and quantitative data sources to assess whether participation in the scenario planning workshop was correlated with an increase in participants' subjective sense of urgency regarding CRM supply risks.

### 4.6. Ethical considerations

All research phases involving human participants (expert consultations and workshop participants) adhered to ethical guidelines. Informed consent was obtained from all participants prior to interviews and the workshop, clearly explaining the purpose of the research, the voluntary nature of their participation, the data recording and storage procedures and the measures taken to ensure anonymity and confidentiality. Participants were informed of their right to withdraw at any time. The audio recordings were securely stored and the transcribed data was anonymised to protect the identities of the participants.

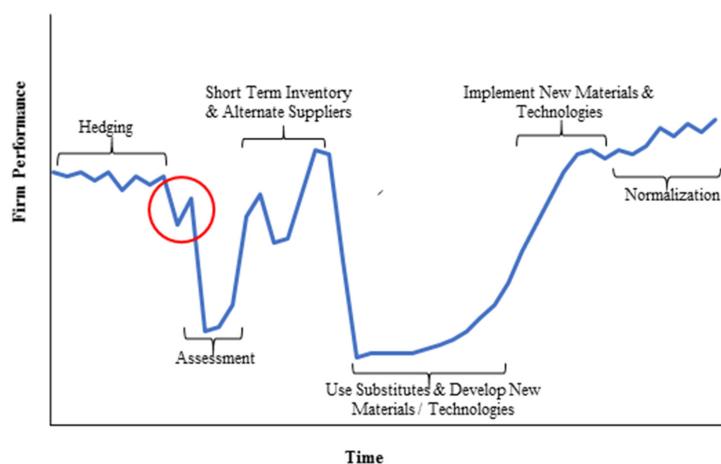
# 5

## SQ1: What are CRM supply risks for companies?

For companies, the most relevant issue concerning material and product supply is relatively straightforward; whether in the future the materials can be supplied in the same quantities and for the same prices as today. Price volatility and the possibility of supply disruptions have shown to be a topic of concern for many companies (Schoolderman, 2011).

This chapter will dive deeper into the factors contributing to the supply risk of CRMs. The chapter will be concluded with an overview of how companies could manage and mitigate CRM supply risks.

As highlighted in the literature review, for example in studies by Sheffi and Rice Jr (2005) and Griffin et al. (2019), how companies react to disruptions is very important for the impact and duration of the effects. High responsiveness can actually create an opportunity to increase market share or cement leadership (Sheffi & Rice Jr, 2005). Figure 5.1 shows the response trajectory of a firm that initially had only used hedging as a mitigation strategy (Griffin et al., 2019). This method proves ineffective when the disruption continues after the initial shock, resulting in another drop in firm performance before other short-term mitigation strategies can be employed, including short-term inventory and alternative suppliers. If the disruption is resolved after that, companies can continue to operate as before. However, if the disruption continues, it can be seen that firm performance will drop again, this time taking much longer to recover. Griffin et al. (2019) concludes from this trajectory that although supply disruptions create predictable impacts across organisations, the outcomes are determined by the response of the individual firm, stressing the need for firm-level risk monitoring and mitigation.



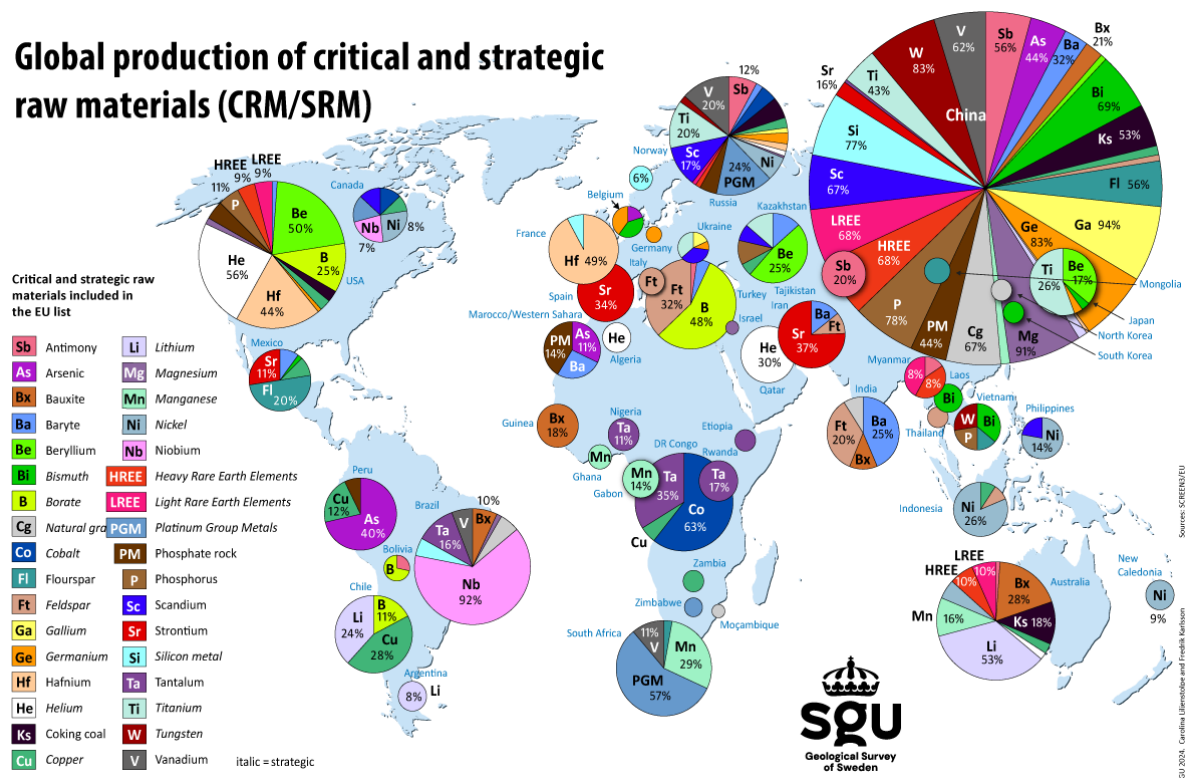
**Figure 5.1:** Trajectory of a response to a supply disruption, showing firm performance against time after a supply disruption at  $x=0$  (Griffin et al., 2019)

## 5.1. Key dimensions of CRM supply risks for companies

### Concentration of supply chains

Supply chain concentration risk refers to the vulnerabilities that arise when there is over-reliance on a limited number of suppliers, geographic concentration in one or more of the stages of the supply chain, or an excessive dependence on specific routes, sub-suppliers or technologies (Mitrarech, 2023). Concentration is one of the key variables taken into the EU criticality assessment, both as global supply concentration, European sourcing concentration (both provided in the Hirfindahl-Hirsch Index, an index to calculate market concentration) and 'Supply-chain/bottlenecks' (Commission, 2020). The latter refers to an extra analysis in case it is unclear in which phase the supply chain is most concentrated (Commission, 2020).

### Global production of critical and strategic raw materials (CRM/SRM)



**Figure 5.2:** Global concentration of CRM production (Geological Survey of Sweden (SGU), 2024).

Mining of most CRM is concentrated geographically, as visible in figure 5.2. This concentration can be attributed to a combination of geological, historical, and economic factors. From a geological perspective, the distribution of CRM is inherently uneven due to millions of years of plate tectonic activity, which has caused certain elements to accumulate in specific regions of the Earth's crust (Groves & Bierlein, 2007). However, the location of mining operations is also heavily influenced by historical trends, which has seen the shift of operations away from developed nations. Nurmi and Molnár (2014) state that in Europe, the development societal and environmental legislation applied to industrial activities, and the protection of remaining pristine ecosystems and agricultural lands led to the suppression or total abandonment of mineral exploration and mining by the end of the 20th century. This explains why for some materials abundant in the earths' crust there are only active mining operations in a few places, most of which concentrated in China. For example, based on geographical spread Rare Earth Elements are not rare at all (Homans, 2010). However, low economic viability of mining operations and environmental concerns have limited operations in many countries, leaving China with a near monopoly on mining capacity (Homans, 2010). The same applies to Silicon, for which only a few countries have built the infrastructure to mine the mineral while it is not geologically scarce (de Pooter et al., 2022). As new mine development takes 7-20 years (Sprecher et al., 2017), geographic concentration of the extraction phase will remain an issue in the coming decade(s).

### Price volatility

Disruptions in the supply of critical materials expose markets to sharp and unpredictable price surges, posing substantial risks to businesses (Griffin et al., 2019). Prices of materials depend on various supply and demand forces which are impossible to accurately predict for the future, as critical materials prices are notoriously volatile (Vogtländer et al., 2019). Prices of materials have often doubled within a year due to shortages or buying crazes (Vogtländer et al., 2019). Apart from that, many critical mineral markets lack transparency, making it difficult for companies to accurately track and negotiate prices. In addition, many CRM markets are characterised by limited transparency, which hinders companies' ability to monitor prices and a bad negotiation position (IEA, 2021). Price volatility can directly impact profit margins, lower working capital, and impact share prices, with studies indicating potential earnings fluctuations of as much as 10–30% (Griffin et al., 2019).

## 5.2. Defining and assessing CRM criticality frameworks and methodologies

For companies in Europe, the EU Commission's criticality assessment is generally taken as a basis for internal criticality assessment. The criticality analysis of the European Commission gives a clear overview of supply risks associated with each material analysed. Aggregating all factors into a single variable makes the materials easily comparable and can help in assessing the susceptibility of materials to supply disruptions as a result of these events. E.g., REE are consistently among the materials with the highest supply risk score (Commission, 2024), and indeed an export restriction from China in 2025 was disrupting the total supply chain of the material (Bradsher, 2025).

However, in the aggregation of variables, details can get lost. For instance, as a proxy for country governance, the World Governance Index is used. This index consists of World Governance Indicators which are aggregates representing six dimensions of governance: Voice and Accountability; Political Stability and Absence of Violence/Terrorism; Government Effectiveness; Regulatory Quality; Rule of Law; Control of Corruption (Bank, 2024). Apart from a statement that the WGI is used as a proxy for country governance, there seems to be no substantiation on the use of this factor in the methodology for composition of the supply risk (Blengini et al., 2017). The WGI has previously been criticised for its construct validity, so whether the indicators measure what they are supposed to measure (M. A. Thomas, 2010). While aggregate variables make it possible to compare two materials on a single number, according to Goddin (2019) it has two serious disadvantages:

1. Aggregated risks mask the reason why the risk exists.
2. Aggregation approach does only consider the raw materials and does not facilitate comparison of compositions containing multiple elements.

To overcome the first of the disadvantages, aggregation of risks, the chapter will continue with analysis of other criticality assessments, gray literature as described in the methodology 4.1.1. The second disadvantage is harder to solve. One of the ways this can be addressed is for companies to perform their own criticality assessment, including materials, composites or even parts and appliances which they might be critical for their operations. The ways companies can assess the criticality of their supplies will be elaborated in this chapter.

### 5.2.1. Companies criticality assessment

Goddin (2019) argues against the use of the EU CRM list in companies, stating it was not designed for firm-level decision making but rather to guide regional policy. Some companies perform their own criticality analysis, incorporating elements they deem most important.

For example, General Electric (GE) has performed its own criticality assessment using variables radically different from those included in the EU-CM. GE's evaluation of its operationally critical materials focused on four key subrisks: the company's proportion of the global supply of the material, the impact on GE's revenue, the availability of substitute materials, and the possibility of passing increased costs on to consumers (Griffin et al., 2019).

One of the main inputs of the supply risk assessments is the concentration of producing countries, both for global production and import to the European Union. In most criticality assessments this is calculated with the Herfindahl-Hirschman index (HHI). The HHI is the sum of the square of the share of each producing country, resulting in a number between 100 and 10,000. As shown in Equation 5.1, the

sourcing concentration is adjusted by a trade parameter, denoted with  $t_c$  (Blengini et al., 2017)

$$(HHI_{WGI, t})_{GS \text{ or } EU \text{ sourcing}} = \sum_c S_c^2 \cdot WGI_{cc} \cdot t_c \quad (5.1)$$

#### Trade Component $t_c$

The trade component  $t_c$  is a variable designed to reflect the extent to which trade-related restrictions may hinder access to a given critical raw material (CRM) from country  $c$ . It accounts for several types of trade barriers, selecting the most restrictive measure in place. It is defined as:

$$t_c = \max(\text{ET-TA}_c \text{ or } \text{EQ}_c \text{ or } \text{EP}_c \text{ or } \text{EU}_c)$$

Where:

- $\text{ET-TA}_c$  reflects the effective export tax imposed by country  $c$ , which may be adjusted downward if a trade agreement (TA) is in force that mitigates such barriers;
- $\text{EQ}_c$  represents any export quota in physical terms (e.g., tonnes) applied to the CRM;
- $\text{EP}_c$  captures the presence of an outright export prohibition for the material;
- $\text{EU}_c$  is a fixed parameter equal to 0.8 for EU Member States, reflecting the relatively lower trade-related risk within the EU.

The component shows that export restrictions are taken into account as important factors for supply risk. It is likely that many materials from China will have a lower  $T_c$  at the next criticality assessment, increasing supply risk scores. Apart from an explanation of the factors, the EUC does not report any reporting on specific values used in its calculations.

#### 5.2.2. Other criticality assessments

The Yale criticality analysis takes the same factors from the EU commission (WGI, Global Supply Concentration) but takes geological factors (Depletion time and companion fraction) and Social & Regulatory Factors (Policy Potential Index and Human Development Index) into account (Graedel et al., 2015).

HCSS (2024) has composed a criticality assessment for the Dutch defense sector. This assessment looks at supply chain risks as the risk of a supply chain disruption. Supply risk is subdivided in two main categories; supply chain risk and geopolitical relations. Supply chain risk is composed of three indicators: Supply concentration (measured by Market share (%) of top three global producing countries (extraction and processing)), Recyclability (as End of Life Recycling Input Rate in EU) and the substitution score. Data from all these indicators is taken from the EU.

The geopolitical relations are composed differently from the EU assessment. This consists of four indicators;

1. Supplier country stability (Fragile State Index (FSI) score).
2. Economic relationship with suppliers (composed of the Trade Intensity Index; a quantitative component, and a qualitative component consisting of trends in investment flows, trade deals and export bans).
3. Political relationship with suppliers (consisting of three sub-categories: the Global Power Index (GPI) measuring the total power worldwide, the relational power measured with the Pardee Formal Bilateral Influence Capacity Index, and a qualitative index taking into account factors such as historical relationship).
4. Military relationship with suppliers (a qualitative index relevant or the defensive industry).

Although these indicators are based on a defense sector focussed criticality assessment, its approach can be used in various sectors as long as the fourth geopolitical indicator is changed.

### 5.3. Categorisation of CRM supply risks for companies

Supply chain risks can be divided into operational risks and disruption risks Tang (2006). Operational risks stem from inherent uncertainties like demand fluctuations, supply variability, and market price changes, typically managed through routine business processes. Disruption risks are of a more sudden

nature, resulting from 'unknowns', factors which cannot be accurately predicted. Disruption risks are often of a short-term nature, nevertheless effects can be dire for companies Alonso et al. (2007).

In recent years, people have become increasingly concerned about the availability of materials, especially as our use of certain scarce resources continues to grow, often for key technologies like renewable energy or electronics. The risk of supply disruptions is becoming more pressing, and these can happen because of two distinct mechanisms: actual physical scarcity of raw material, or short-term shortages caused by events such as political instability, or natural disasters (Alonso et al., 2007).

### 5.3.1. Supply chain concentration risks

As previously mentioned, having limited suppliers exacerbates vulnerability to all other risks.

### 5.3.2. Quantifying Supply Risk and Concentration

The Disruption Potential (DP) metric, adapted from the Herfindahl-Hirschman Index, is used:

$$DP = \sum_j \sum_i S_{ij}^2 \cdot ASI_i \cdot WSI_{ij} \quad (5.2)$$

Where  $S_{ij}$  is market share of country  $i$  in  $j$ 's sourcing,  $ASI_i$  is Ability to Supply Index, and  $WSI_{ij}$  is Willingness to Supply Index. The choice of indicators depends on research scope (Gervais et al., 2025; Yunis & Aliakbari, 2022). Full supply chain transparency is ideal, but often infeasible.

### 5.3.3. Geopolitical risk and country-level instability

**Institutional and Social Disruptions** Failures by markets, firms, or governments can impact resource availability (Alonso et al., 2007).

- **Social Factors:** Poor labor conditions, lack of safety, weak governance, inadequate community infrastructure, and human rights violations represent some of the major risks for disruptions due to social pressures (Althaf & Babbitt, 2021; Montana et al., 2024). These risks can lead directly to disruptions, e.g., strikes due to unsafe labor conditions. Past examples include the South African platinum mining strikes in 2012 and 2014 (Bohlmann et al., 2015; A. Bowman & Isaacs, 2015). Also, they pose risks to companies using these materials indirectly through reputational damage and public pressure.
- **Conflict and War:** Nations that are politically unstable pose a higher risk of mineral supply restriction than those that are not (Graedel et al., 2012). Many resource rich areas are located in war torn regions. This is no coincidence, as the production of valuable minerals can directly lead to conflicts as various parties aim to control the mines (de Pooter et al., 2022). In many cases, export of the materials continues, both through legal and illegal routes. However, there is a risk that conflict escalates, disrupting export of the minerals. DR Congo is the main exporter of cobalt worldwide, having a share of 63% of global production (Commission, 2023b). The region has been war-torn for decades, resulting in a 5th place on the worldwide ranking of fragile states in 2024 (FFP, 2024). In the 1970s, a localised uprising the Democratic Republic of the Congo (then called Zaire) led to a short-term supply shortage as 40% of global production was mined there (Gaustad et al., 2018). The resulting surge in cobalt prices triggered speculative trading, government stockpiling, and significant disruptions within the semiconductor industry (Alonso et al., 2007).

### 5.3.4. Tariffs and Export Restrictions

Tariffs are taxes being raised on the in- or export of specific products. In 2025, tariffs came under the spotlight as President Trump initiated tariffs against various products, which quickly escalated to a trade war between nations (Du & Shepotylo, 2025). The implemented tariffs are mainly import tariffs, aimed at protecting national interests (Du & Shepotylo, 2025).

Export restrictions are measures that restrict export activity. Directly influencing the domestic market, these measures can be taken to improve the domestic security of the product or, as restrictions limit incentives for extra production, they can reduce the negative environmental and social effects of extraction (OECD, 2024). However, measures can also be taken to pressure other countries, especially if the exporting country has a large market share. Interesting to note is that quantitative restrictions on exports are prohibited under the World Trade Organisation under Article XI of the General Agreement on Tariffs and Trade (Organization, 1947). However, evidence shows that this has not prevented countries from taking these measures.

The Organisation for Economic Co-operation and Development (OECD), an association of nations in Europe, the Americas and the Pacific which aims to improve international cooperation, found that export restrictions on raw materials increased more than fivefold in the last decade (OECD, 2024). Their analysis shows that more than 20% of the world's exports of cobalt, REE, tin, palladium, platinum, nickel and other precious metals faced at least one export restriction (OECD, 2024). According to OECD (2024), there can be strong incentives for raw materials producers to exploit their market power dynamics to pursue economic and non-economic objectives, as the digital and green transitions drive a significant increase in demand for several highly geographically concentrated CRMs. Another reason to implement an export restriction can be to stabilise prices. For example, DR Congo had suspended copper exports in February 2025 for a duration of four months (Reuters, 2025a). At the end of the ban, global cobalt prices had increased 60% (Reuters, 2025b).

#### 5.3.5. Economic and financial risks

- **Financial Instability:** Mining is capital intensive. Financial crises or bankruptcies can disrupt production. **Secondary Production Dependence:** Some CRMs are mined as by-products. A decline in demand for the primary material could stop the extraction of the secondary CR as these are not valuable enough in themselves to sustain mining operations.

Future prices depend on various supply and demand forces that are impossible to accurately predict. The prices of critical materials are notoriously volatile. Materials prices have often doubled within one year due to shortages or shopping crazes (Vogtländer et al., 2019).

#### 5.3.6. Operational and logistical risks

- **Chokepoint Vulnerability:** The 2021 Suez Canal blockage caused global delays (Gerson, 2023). Recent disruptions by Houthi rebels in the Red Sea forced costly rerouting (IISS, 2025). Incidents such as these have led many firms to reconsider the design of their global supply chains (Roscoe et al., 2022).
- **Transportation costs and capacity:** COVID-19 caused a 400%+ spike in shipping container prices.

#### 5.3.7. Environmental risks

- **Natural disasters:** Floods, droughts, wildfires, and extreme weather events like hurricanes can halt mining operations. For example, the semiconductor supply chain faced disruptions in 2024 due to such events (Getty, 2024).
- **Water stress:** About 16% of the critical mineral mines and deposits are in places with high or very high water stress, which can lead to a temporary shutdown of mining operations in the event of temporal droughts (Lakshman, 2024).
- **Climate change:** While not a direct disruptor, climate change exacerbates the frequency and intensity of natural disasters (Ghadge et al., 2020). It can also worsen social pressures, such as competition for water resources between mines, agriculture, and local communities, increasing opposition to mining activities (Schoderer & Ott, 2022).

## 5.4. Gray literature

### 5.4.1. Gray literature studied

In previous years, there have been several nonscientific publications addressing CRM supply risks. This gray literature is analysed to triangulate the literature found. This builds on the existing academic knowledge by clarifying the practical application of information found in literature, while similarly adding different perspectives. The gray literature analysed includes reports, analyses, and white papers authored by governmental bodies, international organisations, strategic think tanks, and industry consultancies as introduced in the Methodology, Chapter 4.1.1. The documents studied and the institutions behind them can be found in the Appendix B.

Of the initial list, a further selection was made based on the criteria of the risks listed in the report that were viewed from a company perspective or had relevance for companies. For nine of the 14 studies, it was found that while the report focused on CRM supply risks, the information in the report was aimed at governments or policymakers. Although these reports can help in better understanding the full scope of the issue, this analysis will focus on reports focused on sectors or companies.



This leaves five reports published between 2022 and 2024, originating from institutions (International Renewable Energy Agency (IRENA), The Hague Centre for Strategic Studies (HCSS), and the European Commission's Joint Research Centre (JPC)) and an engineering consultant (ARUP). These particular documents have been identified as offering insights directly applicable to business operations, risk management, or strategic considerations with respect to CRM. For example, HCSS reports list risks for semiconductor and defence sector vulnerabilities with frameworks for company-specific assessments (de Pooter et al., 2022, HCSS, 2024), while IRENA (2023) and Arup (2025) provide geopolitical and energy transition perspectives with case studies relevant to industry. The JPC's work offers detailed supply chain risk analysis for strategic technologies crucial for many businesses (Carrara et al., 2023)).

#### 5.4.2. Key findings from gray literature

Examining the selected gray literature reveals several recurring themes and prominent risk categories with relation to CRMs.

##### Geopolitical and Geo-economic Risks

A strong theme is the translation of broad geopolitical risks into more tangible considerations for businesses.

- **Specific scenario analysis:** Reports like that from de Pooter et al. (2022) move beyond general geopolitical instability to explore specific disruptive scenarios, such as a potential invasion of Taiwan, and their implications for critical supply chains such as semiconductors.
- **Sector-specific vulnerability frameworks:** HCSS (2024) provides an approach to measure supply risks for different parts and products within a specific sector (Dutch defence), assigning values to supply chain and geopolitical relation indicators, offering a relatively accessible assessment method for companies.
- **Geographical concentration:** Vulnerabilities and bottlenecks arising from the concentration of mining, processing or manufacturing activities in a limited number of countries, exemplified by the often cited overreliance on China.
- **Geopolitical risk factors:** The reports outline key geopolitical supply risks, including external shocks (natural disasters, pandemics, wars), resource nationalism, export restrictions, mineral cartels, political instability, and market manipulation, providing case studies relevant to companies.
- **Embargoes and export restrictions:** Explicitly identified by multiple sources, such as the HCSS analyses regarding potential embargoes by nations like Russia and China. The report by the OECD is completely dedicated to historic export restrictions and is based on a database tracking all restrictions to date.
- **Emerging risk factors:** several risk factors came to light that have received less attention in previous academic discussions. These included:
  - The weaponisation of CRM: The deliberate manipulation of material supply chains for the attainment of political leverage
  - Market manipulation: Including practices such as short squeeze, market cornering, and insider trading.
  - Mineral cartels: The potential for co-ordination of production and pricing strategies by dominant producers.
  - Environmental and social pressures: Increasing societal and regulatory concerns that impact the feasibility and social licence of mining and processing operations (Arup, 2025).
  - Technical issues: Operational disruptions, such as power strikes, are considered significant, though sometimes overlooked, sources of supply chain interruption (de Pooter et al., 2022).

##### Detailed supply chain risk evaluation

A notable contribution is the detailed analysis of risks in various stages of the supply chain for specific products and technologies.

- **Multi-Stage Supply Chain Risk Assessment:** The Carrara et al. (2023) methodology evaluates the supply risks for products by analysing the whole supply chain in six potential steps: raw materials, processed materials, components, assemblies, superassemblies, and systems. They evaluated 15 technologies, calculated supply risk using a simplified EU criticality formula, and also considered

geopolitical factors that influence production, trade, partnerships, and substitution. This offers a granular view that is valuable for companies understanding their end-to-end exposure.

- **Focus on Production Industry Insights:** Patrahau et al. (2023) specifically focusses on the insights of the Dutch production industry to advance European mineral security, highlighting practical concerns and perspectives from businesses directly involved in manufacturing.

#### Demand-Side Pressures and Market Dynamics

Rapidly increasing demand, especially propelled by the global energy transition and continuous technological advancements, is frequently identified as a significant risk factor. Although this is often covered in academic literature as a long-term risk resulting from a growing demand due to the energy transition and IT implementations, some of the reports studied list demand risks in the short term. Innovation is mentioned as a key disruptive factor in IRENA (2023), highlighting how innovation can quickly change demand, for example, by changing the chemistry mix in batteries. This shows that maintaining long-term stockpiles could also be a risk, as prices may quickly drop if new technologies are adapted and demand recedes.

#### 5.4.3. Conclusions from gray literature:

Analysis of gray literature provided for a more updated view of the implications of geopolitical tensions on CRM supply, a topic highly relevant for companies active in the Netherlands. The gray literature, especially from policy-orientated think tanks and governmental bodies, often has more freedom in exploring potential future scenarios with a level of detail which is not included in broader academic studies. Examples include analyses of the potential implications of an "invasion of Taiwan" or explicit considerations of embargo risks associated with particular nations. Such focused analyses provide concrete illustrations that can assist companies in policy-making and substantiate or challenge broader academic theories. Although Adams et al. (2017) supports this idea, the authors state that the gray literature can explore "novel fields of inquiry" and address "emergent fields" where the academic literature may be less developed.

### 5.5. Effects of disruptions on companies

The causal relationship between geopolitical events and company impacts has been drawn by Vogtländer et al. (2019). A (geo)political event (e.g., export ban, social unrest in mining countries, strikes, etc.) results in supply chain disruptions or a sudden technical breakthrough. Due to limited stock in the logistics chain, this will lead to materials shortages. In the free-market economy, this will result in higher prices, rising very rapidly, since all market players try to buy material stocks that are available. Companies that need the material will see risks to their profit margins because they cannot quickly increase the sale prices without losing market share. In case prices spike too high or supply is disrupted too long, this can eventually result in bankruptcies (Vogtländer et al., 2019).

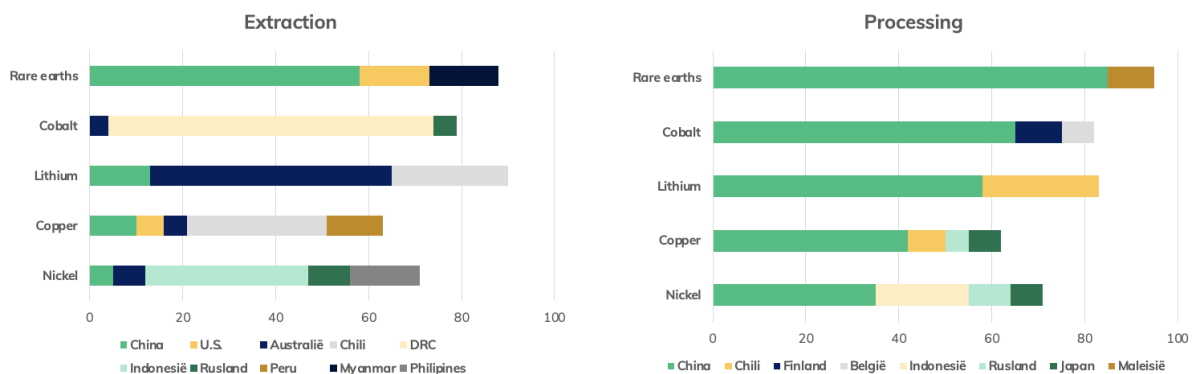
In the field of CRMs, it becomes apparent that countries and companies are rather crisis-prone. The REE crisis of 2010 quickly led Japan to introduce a package of crisis measures worth more than a billion dollars, 15 years later it is still over 60% dependent on China for REE supply (Terazawa, 2023). Although at the time the unprecedented export ban shocked the world, it has not been a catalyst for change, as the dependence on Chinese refined REE has only increased (Terazawa, 2023).

Hendricks and Singhal (2005) found that companies lose an average of 33–40% of stock returns over a three-year period due to supply disruptions. Interestingly enough, Hendricks and Singhal (2005) highlight that this underperformance is already evident in the year leading up to supply disruption, showing a link with the preparedness or position of companies. Apart from that, after a disruption, companies face an income decrease of more than 100%, lower sales growth, and higher costs (Hendricks & Singhal, 2005).

An example showing the benefits of adequate disruption management is a case study by Sheffi and Rice Jr (2005) that describes a fire at a manufacturing plant that disrupted the supply of phone chips in early 2000, affecting both Nokia and Ericsson. Nokia responded proactively by securing alternative suppliers and adjusting its product designs to fit different chips. In addition, it maintained close communication with the original manufacturer, showing good supply relationships. In contrast, Ericsson was slow to act and was unable to secure an alternative supply in time. As a result, the company experienced an estimated revenue loss of \$400 million and eventually resigned from the consumer cell phone market.

### 5.5.1. Chinese export restrictions

In the field of CRM, China has positioned itself as the absolute centre in the last few decades. Table 5.1 shows the materials on the EU CRM list in which China is the largest global producer. It is apparent that China has developed itself over the whole spectrum of materials, having majorities in extraction (materials with a \*) to near-monopolies in processing of other CRM. Figure 5.3 shows that even for SRM in which China has relatively small extraction shares, it has evolved to be the largest processing power in the world. This is in line with general development theory, which states that as countries develop, they look to maximise the value of their natural resources by exporting finished products rather than ores or even refined materials.



**Figure 5.3:** China's global share of extraction (left) and processing (right) of selected CRM (Staff, 2023)

In 2010, China implemented an embargo on neodymium exports to Japan as a reaction to a territorial dispute. However, due to crime syndicates that smuggled almost half of the REE production from China out of the country, the embargo did not cause an absolute stop on export. Since 2010, China has cracked down on these crime syndicates and nationalised all production and combined all facilities into a single organisation; China Rare Earth Group, making current embargos more effective (Bradsher, 2025).

In December 2024 China banned the export of gallium, germanium, antimony and superhard materials to the United States, as well as required a review of end-use for graphite exported to the United States (Lv & Munroe, 2024).

These numbers under-represent China's influence in the global CRM trade. Many mines and processing facilities are owned by overseas companies (Teer & Bertolini, 2022). For example, most cobalt mines in the DRC are owned by China. In 2020, Chinese (state) owned companies owned or had a financial stake in 15 of 19 cobalt mines in the DRC (Lipton & Searcey, 2022). Mapping the exact ownership of each step in the supply chain of the CRMs in the EU criticality list is far out of the scope of this thesis. However, it can be concluded that even for materials in which China does not have a natural monopoly because the material is not found in China, it has found a way to ensure a steady supply of material can be imported to China. China is the world's largest importer of raw or unprocessed nickel, copper, lithium, cobalt, and rare earths. However, it has strategically dominated extensive midstream and downstream processing operations for many critical materials (IRENA, 2023).

## 5.6. Non-supply chain CRM risks for companies

Although supply chain disruptions pose the most immediate and impacting risk for companies, there are several other risks associated with the current use of CRM. Strategic market risks and ESG induced risks are the most directly impacting, and these will be briefly introduced in this section.

### 5.6.1. Strategic market risk

The unsustainable and linear use of CRM could limit access to future markets or partnerships, as customers may require full material traceability. For example, the Ministry of Economic Affairs and Climate Policy (EZK) is incorporating circularity requirements into the procurement processes for wind farms and solar panel development. Over time, this approach can be gradually extended to other sectors such as defence, telecommunications, or construction (Ministerie van Economische Zaken en Klimaat, 2022).

**Table 5.1:** Critical Raw Materials for which China is the largest global producer (2016-2020 average share) (IISS, 2025)

Material	China's Share (%)
Antimony*	52%
Arsenic	44%
Baryte	32%
Bauxite (alumina/aluminium)*	56%
Bismuth	69%
Coking coal*	69%
Copper*	38%
Fluorspar	56%
Gallium	94%
Germanium	83%
Graphite – battery grade	67%
Lithium – battery grade*	56%
Magnesium	91%
Manganese – battery grade*	58%
Nickel – battery grade	33%
Phosphorus	78%
REEs for permanent magnets (Ce, Dy, Gd, Nd, Pr, Sm and Tb)	68%
Scandium	67%
Silicon metal	77%
Titanium metal	43%
Tungsten*	86%
Vanadium*	62%

### 5.6.2. ESG

As mentioned in the Introduction, many CRMs are associated with high emissions. The Carbon Border Adjustment Mechanism (CBAM) imposes a carbon tax on importers of products with high carbon footprints. The CBAM is currently limited to a few high impact materials such as steel, cement, and aluminium. However, there are plans to expand the range of materials covered (Everledger, 2023). One of the goals of CBAM is improving the competitiveness of more sustainable production and recycling facilities in Europe (Kemp & Furman, 2025). Shifting to less carbon-intensive products might reduce the risk of having to report and pay taxes under the CBAM. In addition, the use of CRMs is associated with unethical labour practices, environmental degradation, or conflict zones can damage the brand value (World Bank, 2021).

## 5.7. Mitigating measures

The over-arching goal of critical material mitigation strategies should be to make a transition from a linear 'take-make-use-dispose' economy to a circular economy (Offerman, 2019). Improving circularity is one of the pillars of the new National strategy for raw materials (Nationale grondstoffenstrategie) published by the Ministry of Economic Affairs and Climate Policy. Through this policy, companies can benefit from access to funding and collaboration opportunities (Ministerie van Economische Zaken en Klimaat, 2022).

These strategies are often of technical nature; however, implementation may depend on novel business models, legislation, and acceptance. (Offerman, 2019) lists 9 technical approaches. 5 of which relate to the extraction or recycling phase and are thus not the most relevant for companies which do not physically handle any raw materials, and are therefore combined. Two categories, 'improve the resource efficiency of materials' 'Maximise the properties (functionality) per unit of material' are categorised under substitution by later sources. This leaves the following categories:

1. Circular product design
2. Substitution
3. Recycling
4. Supply Chain Risk Management
5. Other

### 5.7.1. Circular product design

The idea of circular product design is highly relevant, as it can ensure that CRM risk mitigation goes hand in hand with a positive environmental impact. Peck (2016) mentions various strategies such as design for disassembly and re-manufacturing to enhance material efficiency and reduce CRM dependency.

### 5.7.2. Substitution

For substitution, SCRREEN (2019) identify four main categories:

1. Substance-for-substance substitution
2. Service-for-product substitution
3. Product-for-product substitution
4. New technology adoption

#### Substance-for-substance substitution

A company may substitute one alloy for another, develop a completely new alloy, minimise waste through improved material use, or reduce the total material required by improving material efficiency (Griffin et al., 2019). However, for substance-for-substance substitution, the difficulty lies in the fact that most materials are critical due to their low substitutability (Graedel et al., 2013; Peck, 2016). Substitutability is taken into the formula for both supply risk and economic impact in the Commission (2023b) criticality assessment, so materials which are easily substitutable are likely not assessed critical in the first place.

#### Service-for-product substitution

Service-for-product substitution can be a viable option to reduce material demand. This is part of the dematerialisation strategies, as described in Gaustad et al. (2018), which refers to the reduction of materials needed to provide the desired economic service. This includes shared economy initiatives, which reduce the number of products necessary to fulfil the same function, e.g., a number of shared cars in a neighbourhood. Other options include leasing products instead of selling them, through which a company can ensure that parts and materials remain in its value chain (Ashby, 2016).

#### Product-for-product substitution

This strategy can be viable if products containing certain CRM or parts that are at risk of supply disruptions can be replaced with more easily available products.

#### New technology adoption

This approach has been used by Philips, who reduced the helium demand for its MRI machines from 1500L to 7L through adoption of a new sealing method. In addition, the permanent magnets on the machine are 900 kg lighter than its predecessor (Philips Healthcare, n.d.). Unlike other MRI machines, they do not have to be filled regularly, reducing costs and risk for hospitals. In addition, as thousands of machines are sold, this shows the opportunity of design to reduce CRM demand.

### 5.7.3. Recycling

If proper recycling infrastructure is in place, the use of secondary raw material could reduce supply-risk, as well as demand of raw materials (Ministerie van Economische Zaken en Klimaat, 2022)

Recycled materials can serve as an alternative material source, reducing the impacts from disruptions in the primary supply chain (Santillán-Saldivar et al., 2021). At this moment, recycling rates of most critical materials are low as recycling is mostly commercially driven, and processes are only viable if both quantities and concentrations are high enough (Bastein & Rietveld, 2015). Previous disruptions have indicated that a long period of sustained material constraints will be necessary for a system to naturally evolve towards sufficient levels of circularity (Sprecher et al., 2017). However, there is currently progress being made in the field of recycling, improving recycling possibilities in the EU. E.g., Ionic Technologies, an Australian company, expects to produce 400 tonnes per year of separated rare earth oxides at a plant in Belfast (Webber, 2025). While this is the first plant which is able to do so outside of China, Webber (2025) expects many companies to follow.

From a Circular Economy perspective, CRMs tend to be overlooked within circular initiatives when using mass-based indicators as Key Performance Indicators (KPI's) , e.g. for recycling targets, as CRMs are often used in comparatively small amounts (Cimprich et al., 2023).

#### 5.7.4. Supply Chain Risk Management

Traditional supply chain management aims at reducing supply chain complexity and lead times, minimising costs, improving responsiveness and optimising operational efficiency (Giannakis & Papadopoulos, 2016). CRM risk management strategies aim for almost exactly the opposite, as it is often advised to increase the number of suppliers, spend extra on materials if this could reduce supply risk, and move away from operational efficiency by retaining stockpiles. However, these mitigation measures alone do not tackle the underlying dependence on CRM in the value chain. Therefore, a different approach is necessary. Giannakis and Papadopoulos (2016) argue that sustainability-related risks, including CRM issues, should be embedded in SCRM. This offers a structured entry point for CRM awareness for companies who have a structured SCRM in place.

#### 5.7.5. Other

##### **Diversification of suppliers:**

diversifying suppliers geographically can decrease dependence compared to sourcing from a single origin. However, this does not necessarily improve environmental impacts, and in case of global disruptions of a material this would still affect the company.

Reshoring can increase sustainability and security for sourcing materials Ashby (2016). Environmental co-benefits can follow from shifting away from high-emission production regions Cohen (2023).

##### **Stockpiling**

Holding strategic reserves and stockpiles is often mentioned as a solution for companies willing to reduce their supply risk. Holding reserves can buffer short-term disruptions, but must be managed carefully. Apart from that, holding stockpiles can also be a financial risk in itself due to the volatile nature of CRM prices, which can also drop significantly within short time spans (IRENA, 2023).

##### **Managing Price Volatility**

Given the inherent price volatility of CRMs (Vogtländer et al., 2019), financial risk management strategies (e.g., hedging, long-term contracts) are also relevant, although distinct from mitigating physical supply disruptions. Griffin et al. (2019) mentions that long-term contracts do not always ensure commodity delivery when actual physical disruptions occur.

#### **Policy mitigation actions from a company perspective**

Some mitigation actions can be copied and scaled from government policy to company policy. For example, increasing the number of suppliers is mentioned as one of the key strategies for governments, as well as companies. However, other mitigating actions are only relevant for companies. These will be shortly mentioned in this section.

- Refining capacity: Building new refining capacity requires major investment and faces regulatory and human capital barriers, and is therefore unlikely to be initiated by companies who do not have this as their core business (Teer & Bertolini, 2022).

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## 5.8. Initiation of strategy

As listed in 5.7 there are several strategies companies can adopt. However, for companies new to the subject of CRM how an appropriate strategy is chosen.

An important first step for companies is to understand which CRM in their value chain, and what materials are most critical for their company. As introduced at the start of the chapter, and as stated by Griffin et al. (2019), monitoring and mitigation of CRM use is not only possible, but necessary. There is not a one size fits all solution to reduce CRM dependence for companies. However, literature shows mapping the supply chain is an important first step for all companies.

#### Mapping of supply chain

The first step which has to be taken by any company willing to mitigate CRM supply risk is mapping which CRMs are in its value chain (Kolotzek et al., 2018). They have designed a 4-step process for companies for assessing and managing CRM risk, of which the first step is the identification of which CRMs are

involved in the value chain of the company. When doing this, companies should have already analysed the contents of their inflows and preferably have material passports of the products they purchase, which specifically describe the contents and origins of materials that are in the product (Zhang & Seuring, 2024). This analysis can be quite complicated, as products such as smartphones contain over 50 different metals, including critical materials such as iridium and silicon (Commission, 2023b). This first step should not be viewed too lightly, as companies can have thousands of suppliers. Industry specific papers or reports can facilitate this task. Also, there are certain tools to assist companies with initial assessment, such as the 'Grondstoffenscanner'. A webtool designed by the Dutch Enterprise Agency, which can be used to identify which critical materials are certain products they purchase ((RVO), 2024).

## 5.9. Conclusion

This chapter has answered the first subquestion: 'What are the main supply risks associated with companies' dependence on CRMs?'. This research concludes that the most immediate and impactful threats for downstream companies stem from acute vulnerabilities created by supply chain concentration.

Disruptions in the past few years have shown that single events can stem entire trade networks in the world. China has facilitated many CRM to Europe for years, building up near monopolies for many materials and processing industries. This has brought China in a strategically dominant position, where a single export ban can stem near total export of a material.

Knowledge of these risks is essential in order to fulfil the expert role for construction of the communication tool implemented in SQ3. Besides, the overview of risks and mitigation actions provide valuable information for companies reading this thesis.



# 6

## SQ2: What communication tools can increase risk awareness in companies?

### 6.1. Introduction

Due to day-to-day preoccupations, companies lack awareness of distant risks and often do not feel a sense of urgency for abstract, long-term risks. Several tools have been developed to help managers identify, assess and mitigate risks.

As outlined in the overall research design in the Methodology, in Chapter 4, this chapter addresses the second sub-question (SQ2) through the process of identifying, evaluating, and selecting a communication tool. Thereafter, it is described how the tool is methodologically adjusted to be used as the central intervention in this researches' Action Research cycle.

#### 6.1.1. Methods and tools for creating risk awareness in a business environment

There are several methods used for exploring and understanding risks in a business environment. Koessler and Schuett (2023) separates the tools into three different categories; risk identification, risk analysis, and risk evaluation.

Risk identification tools can help companies determine which risks are relevant to their companies. This does not align with the research purpose, as the aim is to help companies better understand a specific risk. The relevant category for the purposes of increasing awareness is risk analysis, as these tools help companies to better understand what they are facing.

The following tools are considered:

1. Serious games
2. Monte Carlo Simulation
3. Educational training
4. Pre-mortem
5. Risk-exposure calculator
6. SWOT Analysis
7. Scenario planning

#### 6.1.2. Serious games

Serious games are a relatively new field that aims to improve learning through participation in interactive games. The method has proven to be successful in educating about cyber security risks (Hart et al., 2020). A serious game educating CRM usage has also been designed and tested by Whalen and Peck (2014), and showed success in educating participants about how CRMs are used and acquired. Another

game, 'chain of command' has shown to increase awareness among participants on sustainable supply chain management (Cuesta & Nakano, 2017). While the process of designing an producing a game can be expensive, simpler, proof-of-concept versions can be low-cost.

#### 6.1.3. Monte Carlo simulation

Monte Carlo simulation can quantify the effects of risks and uncertainty in project management by offering statistical indicators for project performance. The focus is on low-probability, high-impact risks that might be overlooked (Qazi & Simsekler, 2021). By running thousands of simulations, the Monte Carlo simulation works especially well to find high-risk outcomes that other methods do not (Farooq et al., 2024). However, Monte Carlo simulation needs quantification of the relevant variables, including probability allocation. This is often done by interviewing large numbers of experts, which might be a threshold for many companies (Farooq et al., 2024). While academically robust, this tool was deemed unsuitable as it will require large numbers of data from the companies participating.

#### 6.1.4. Educational training

In order to build knowledge, a straightforward approach is to provide decision makers with information through training. Research by Peck (2016) showed that most companies preferred to be passively informed about CRM developments. The effectiveness of passive information reception on CRM risk awareness has not yet been empirically validated. However, from a psychological point of view, previous research by Natter and Berry (2005) has shown that active learning results in higher risk awareness than passive learning.

#### 6.1.5. Pre-mortem

A pre-mortem is an exercise which companies can undertake to better deal with uncertain futures. By working back from a bankruptcy a company can analyze the factors that led them there and compose mitigation actions to prevent that future (Ghez, 2019). It is mostly used as a management tool to prevent project failure by considering risks from the start. However, its effectiveness is never academically substantiated.

#### 6.1.6. Risk exposure calculator

A tool in which companies can input known product and material data, and get an overview of the risks they are exposed to. Translating CRM risk as described by the European Commission into company relevant information through an assessment tool which companies can use to obtain an insight into the risks, can be a practical way to increase company awareness of their exposure to the risks. Even more practical would be a tool which financially quantifies the risks. Slowinski et al. (2013b) concluded that the most effective way of communicating CRM risk was by calculating the total financial damages which would result from supply of a certain material stopping. While some studies have undertaken an effort to calculate this risk at a company level, detailed knowledge and understanding of an organizations' financials is necessary to make any substantiated prediction.

#### 6.1.7. SWOT Analysis:

A strategic planning tool analyzing Strengths, Weaknesses, Opportunities, and Threats, useful for identifying internal and external factors that could pose risks. This has been done by producers who are involved with CRMs, for example by performing a SWOT analysis on magnets containing rare earth elements (Bonfante et al., 2021) or nickel in batteries (Haryadi et al., 2024). However, if no-one knowledgeable of CRM risk is present in the session when the SWOT is conducted, it could be that this risk is missed in the analysis, as the SWOT builds on the knowledge of people present. As the research aims to increase awareness where it is lacking, relying on pre-existing knowledge is fundamentally misaligned with the research objective.

#### 6.1.8. Scenario planning

Scenario planning (SP) is a management tool in which multiple future scenarios are conducted and discussed. Through SP, managers can be helped to recognize and reflect on the uncertainties presented, assisting in developing strategies that are resilient under varying conditions (Amer et al., 2013; Cairns & Wright, 2017; Schoemaker, 1995; van der Heijden, 1996). Multiple studies show that SP is a powerful tool for increasing awareness and helping participants to better understand how different conditions can develop (Schwenker & Wulf, 2013; van der Heijden, 1996).

## 6.2. Selection of applicable tool

The selection of an appropriate communication tool was guided by a set of criteria developed to ensure both practical application and academic validity. As the literature review revealed that there was no established framework for this specific purpose, the author formulated these criteria to systematically evaluate potential tools. The criteria and their corresponding rationales are described in Table 6.1.

**Table 6.1:** Criteria used for the selection of a communication tool which increases risk awareness

Criteria	Rationale
Low budget	No need for funding ensures accessibility
Replicability	Facilitates the use across different companies and sectors
Feasibility within time scope	Time is limited within a thesis process, maximum of 6 weeks for construction of the tool
Academically supported	Methodology is supported by established academic reports
Proven effectiveness in other risk or awareness context	Previously validated for increasing awareness
Novel application for CRM awareness	Ensures research contributes a new insight or distinct approach
Managerial relevance	The tool should provide practical insights for participants
Facilitation by external parties	The tool can be constructed and facilitated by someone not employed by the target organization
<b>For participants:</b>	
Accessible without pre-existing knowledge	The tool should be accessible to participants from all levels of the organization
No preparation required	To increase practicality of scheduling and deployment of the tool
Maximum duration of 1/2 day	The more time required, the higher the obstacle for participation

**Table 6.2:** Evaluation of tools for CRM Awareness

	Low budget	Replicability	Feasibility within thesis time scope	Academically supported	Proven effectiveness	Novel application for CRM awareness	Managerial relevance	Accessible without pre-existing knowledge	Maximum duration of 1/2 day
<b>Serious games</b>	Maybe	Yes	Maybe	Yes	Yes	No	Yes	Yes	Yes
<b>Monte Carlo Simulation</b>	Yes	No	Yes	Yes	Yes	Yes	Yes	No	Yes
<b>Educational training</b>	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes
<b>Pre-mortem</b>	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes
<b>Risk-exposure calculator</b>	Yes	No	Yes	Maybe	Maybe	Yes	Yes	Yes	Yes
<b>SWOT Analysis</b>	Yes	Yes	Maybe	No	No	Maybe	Yes	No	Yes
<b>Scenario planning</b>	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Maybe	Maybe

Based on the systematic evaluation against the established criteria, Scenario Planning (SP) emerges as the most suitable tool for this research. SP's proven effectiveness in helping managers recognise and reflect on complex uncertainties, combined with its strong academic support, made it the superior choice.

However, the evaluation also recognised that traditional SP methodologies have two notable limitations that required proactive mitigation in the workshop's design. Firstly, initial research shows the length of a

scenario planning session can take multiple days to months. Therefore, a more condensed format has to be conducted. Secondly, SP requires knowledge to actively participate in the scenarios. By adapting the methodology to resolve these challenges, the condensed SP workshop provides a robust and feasible approach for this research.

## 6.3. Scenario Planning

This chapter will examine whether Scenario Planning (SP) can theoretically be used as a tool to increase awareness and a sense of urgency of supply risks of Critical Raw Materials (CRMs). This chapter aims to explore the method in order to construct a fitted methodology for constructing a SP workshop at companies for increasing risk awareness.

## 6.4. Basis of Scenario Planning

In its basis, SP is building plausible, coherent and credible alternative stories about the future. These are designed to help companies challenge their assumptions and develop their strategies (G. Davis, 2002). The origins of scenario planning can be found in the 1950s and 1960s, when scenario building was first used by the US military (C. Thomas & Chermack, 2019). Its power as a management tool, famously pioneered by Shell, lies in its use of narrative and storytelling to make complex uncertainties tangible (G. Bowman et al., 2013; Cornelius et al., 2005).

### 6.4.1. When Scenario Planning can be used

During periods of turbulence, unpredictable uncertainty, novelty, and ambiguity, organizations frequently experience serious challenges that threaten existing value chains, communities, and even whole fields of endeavor. Such conditions can be unsettling and destabilizing at different levels. But they also present opportunities for organizations to reframe their strategies and innovate (Ramírez & Selsky, 2016). For SP, it is important to make a distinction between the immediate business environment in which an organization exists, which includes the companies suppliers, customers and competitors, and the broader environment which is beyond the companies' influence (Ramírez et al., 2017). SP is about exploring how the latter can influence the immediate business environment, and how the company and its influence sphere can deal with that.

The scenarios are presented as narratives with a threefold outcome: strategic planning for decision-making, increase of awareness for uncertainty, and a change of the mindset that could lead to implementing specific strategies (Araújo & Casimiro, 2023). All of these align with the objectives set in this thesis, and will be further examined in the following section.

### 6.4.2. Goals and functions of Scenario Planning

#### Awareness

The role of SP is to help managers recognize, consider, and reflect on the uncertainties. Therefore, it is mentioned by many authors that SP can serve as a powerful tool to increase awareness and understanding of how different conditions will develop along different paths and anticipate them (van der Heijden, 1996).

The goal of scenario planning is to engage decision-makers in meaningful dialogue that increases understanding of the issues presented, after which they are guided into linking these issues to the future of their organization. This helps in broadening their perceptions about the types and natures of situations that could emerge, as well as seeing how these affect their own situation (C. Thomas & Chermack, 2019). The goal of scenario planning is not to develop a specific solution but to engage decision-makers in meaningful dialogue to understand critical issues for the organisation's future and broaden perception about situations that could erupt (Olivares-Aguila & ElMaraghy, 2021).

#### Communication

Scenarios can have a communication function on different levels. They can themselves be generated as part of communicative processes, stimulating a discussion which helps to build towards a common, shared understanding of a problem while promoting an exchange of ideas and the integration of different perspectives concerning a topic (Kosow & Gaßner, 2008). However, this process is time-consuming (Cordova-Pozo & Rouwette, 2023), and requires informed participants and experts to be involved (Kosow & Gaßner, 2008). On the other hand, scenarios can also be used to generate communication and to inform about topics and priorities, thus expanding the understanding of topic areas (Kosow & Gaßner,

2008). This function is highly relevant in this thesis, as casting light on CRM risks and enriching debate about these matters can build towards organizational risk awareness.

Scenarios offer the possibility to combine quantitative data with qualitative input, enabling scenario planners to incorporate results from other forecasting techniques and allow for communication which is less scientific and numbers-based, building more on a contextual understanding (Cornelius et al., 2005). Finally, scenarios can help stretch managers' mental models by explicitly confronting them with their own biased viewpoints (Cornelius et al., 2005).

#### Composing and testing strategy

Kosow and Gaßner (2008) list strategic planning and discovering action to be taken as one of the key functions of scenario planning. In scenario-based decision making, strategic decisions are tested for robustness against a series of scenarios describing plausible future worlds (Harries, 2003).

#### 6.4.3. Theoretical approaches

The main schools of thought in scenario planning include the qualitative Intuitive Logics (ILM) and Oxford approaches, and the quantitative Probabilistic Modified Trends (PMT) school. The selection of a method depends on the nature of the uncertainty being addressed (Amer et al., 2013).

Quantitative approaches like PMT, which use historic data and expert-assigned probabilities to extrapolate future trends. The main argument against probabilistic methods is that assigning likelihoods is meaningless in a constantly changing world (Cordova-Pozo & Rouwette, 2023). Therefore, quantitative approaches are deemed less suitable for the complex, unpredictable nature of CRM supply risks.

Therefore, this research adopts the qualitative school. The ILM approach is chosen, as this approach identifies impacting uncertainties, the so-called driving factors which cause supply disruptions, and generates coherent stories of how hypothetical sequences of events can impact society (Amer et al., 2013). Other qualitative approaches, such as the Oxford approach, rely on a facilitated process of discussion and consensus-building among participants, which is not possible within the scope of the workshop (Bradfield et al., 2005). The focus on narrative stories to explore uncertainty aligns with the goal of increasing participant awareness and is consistent with the framework used by Cairns and Wright (2017).

#### 6.4.4. Lessons learned from practice

This section critically analyzes three key case studies to extract practical lessons that directly informed the design of the SP workshop in this research. The case studies analyzed are from Shell (Cornelius et al., 2005), British Airways (Moyer, 1996) and a government district (Blekinge, Norway) (Thomson et al., 2020).

#### Goal of a mindset shift instead of making predictions

The most important lesson from Shell's pioneering in SP is that the value of SP lies in helping managers improve and understand driving forces behind an unpredictable future, not predicting the future (Cornelius et al., 2005). The notion that participants have to understand that scenarios are likely erroneous is stressed in literature (Wack, 1985). This finding is central to this study's objectives. The workshop was therefore designed not to predict future materials prices but rather deepen participants' understanding of the geopolitical and economic forces that may create supply risks. This will also be clearly communicated to participants. This aligns with the goals of increasing awareness and a sense of urgency, rather than predicting power.

#### Empirical evidence of success

SP has proven to provide Shell a competitive advantage during crises such as the turmoil that followed both the first and the second oil shocks in 1973 and 1979, which has enhanced the credibility of the method within the company and also provided empirical evidence of the success of managing uncertainty through scenario thinking (Cornelius et al., 2005). The British Airways SP has proven successful in assessing existing strategies and developing new strategies using the 2x2 matrix visualizing different scenarios. The process concluded with discussions identifying necessary capabilities, actions and responsible stakeholders for implementation (Moyer, 1996).

Making the step from SP to practical strategising is important, keeping momentum in the company from the moment a sense of urgency is felt. This approach will be adopted in the SP workshop, having participants list the questions remaining, first actions required and the stakeholders which will be responsible for implementation.

#### Lean approach of workshop

Although it is mentioned that the SP process was designed to be flexible in time and wishes so certain elements could be emitted, the British Airways case, as described, took the equivalent of 2 man-years in preparation and required much time of participants to decide which issues would be significant for the company. Therefore, the case study from the Blekinge municipality shows an interesting alternative perspective, as their SP workshop was condensed to just one day, a so-called rapid-SP. designed for agility and efficiency. Variables were pre-determined by the preparation team (Thomson et al., 2020). Evidence that this approach achieved desired effects within the limited time spend with participants supports the notion that the SP workshop can be executed in a highly condensed format.

### 6.4.5. Limitations and mitigating actions

#### Time requirements

One of the concerns of SP highlighted in during selection of a tool is the time requirements of the SP-process. Previous SP trajectories have lasted as long as weeks. There is an optimal to be found here in the time planned for the workshop. More time allows for deeper engagement with the future uncertainties, scenarios and mitigation strategies. However, the more time people have to commit, the less likely it is to get managers and other key decision makers involved as they are generally preoccupied. Especially if the workshop specifically addresses a risk they are yet unfamiliar with, it is unlikely they will commit a full day or longer (Cairns & Wright, 2017). This allows the workshop to be more condensed, with an emphasis on risk and opportunity recognition and conducting mitigation strategies.

#### Lack of initial knowledge

A further limitation of using Scenario Planning, as mentioned in the tool selection section, is the potential lack of foundational knowledge of participants. As noted by Cairns and Wright (2017), if participants are entirely unfamiliar with a topic, they may struggle to engage with the scenarios or understand their implications. This could undermine the workshop's goal of increasing awareness.

To mitigate this, the designed intervention includes an introductory presentation at the start of the workshop. This 45-minute presentation will provide all participants with a common baseline of knowledge, covering the definition of CRMs, key supply chain vulnerabilities, and the geopolitical context, drawing on the findings from SQ1. This ensures that all participants, regardless of their initial familiarity, can engage meaningfully with the scenarios, thereby maximizing the potential effectiveness of the intervention. The workshop is intentionally designed to be not company or sector specific, as to ensure the replicability of the tool. The presentation is provided in the additional materials.

#### Focus on long-term strategies

Traditionally, scenarios were used to conduct long-term strategies, with time-horizons set at 10-30 years. However, was first argued by Marren and Kennedy Jr (2010) that there is no logical reason to restrict SP to extremely long-term decisions, and that the tool is very suited to make short-term decisions in an uncertain environment as well. Since then, scenarios are used to deal with the inherent uncertainty in short-term disruptions (such as for example flooding, COVID 19, terrorist attacks, or a financial crisis) (Cordova-Pozo & Rouwette, 2023). This supports the use of SP to strategise for sudden CRM disruptions.

#### Evaluation of effectiveness

A major obstacle to the assessment of effectiveness of SP as a tool is that many projects are not evaluated (Cordova-Pozo & Rouwette, 2023). This is ascribed to a lack of reporting guidelines and a proliferation of SP approaches. Due to the often psychological effects of an SP project, e.g. increased awareness, its causal effects on decision making and results are often hard to prove (Cordova-Pozo & Rouwette, 2023). This research aims to mitigate this limitation in two ways; by both reporting on the process and assessing impact on the participants through pre- and post-workshop questionnaires. The reporting will be achieved through including all construction reporting in the appendix: this includes a summary of the steps followed for constructing the scenarios, the workshop outlines including the presentation used, and a description of the evaluation process in the methodology.

One other limitation mentioned is that SP results are often self-reported by companies, meaning the results are often emphasizing the positive effects on decision making. This research aims to partly mitigate this bias as the results are evaluated by an external researcher. However, the questionnaires are self-reported, making a possible positive self-evaluation bias one of the limitations during this research, illustrated in the discussion 9.3.

## 6.5. Scenario planning methodology

The SP methodology applied in this thesis consists of five phases; (i) the development of the scenarios, (ii) the participatory evaluation of the SP in the form of a pilot workshop, (iii) revisions applied to the SP workshop, (iv) the participatory execution of the SP in practice and (v) reflection on the impacts of the scenarios on the participants involved. The first phase will be described in this chapter, the other 4 are part of the methodology for SQ3 4.2.

The conceptual framework of the first phase (scenario development) follows the eight-stage approach of Cairns and Wright (2017). Steps three, four and five are combined as de Pooter et al. (2022) already provided an impact-probability matrix in their report, and clustering of drivers was assisted by using the graphical format of the uncertainty/impact matrix. This leaves the six steps outlined in the following section.

### 6.5.1. Scenario development

#### 1. **Setting the agenda: defining the focal issue and setting a time horizon.**

The issue covered in the scenarios will be CRM supply risk. The time covered will be 3 years. In previous research this has been suggested to be the minimal time horizon for an effective SP session (Amer et al., 2013). There is an optimum to be found between the psychological distance, which optimally is minimized as explained in the Theoretical framework, a realistic time-scope for the geopolitical context to change, and a realistic time-scope for the company to undertake any substantial mitigation strategies. 3 years is therefore chosen as a realistic time-scope to meet these concepts, and fits within the 1-5 year scope set in this research.

#### 2. **Determining the driving forces: identifying the critical drivers through literature review and expert consultations.**

The base of the driving forces has been the report '*Reaching breaking point, The semiconductor and critical raw material ecosystem at a time of great power rivalry*' by de Pooter et al. (2022). This report interviewed 49 experts, aiming to find the main threats to the supplies of CRM for semiconductors. They conducted a list of 10 main threats with probability factors for the next 5 and 10 years. While focused on semiconductors, comparison with the analysis from SQ1 showed these risks are all highly relevant for CRM in general. Combination of the risks listed in SQ1 and the HCSS report resulted in a list of 10 driving forces, as visible in figure 6.1 (in Dutch).

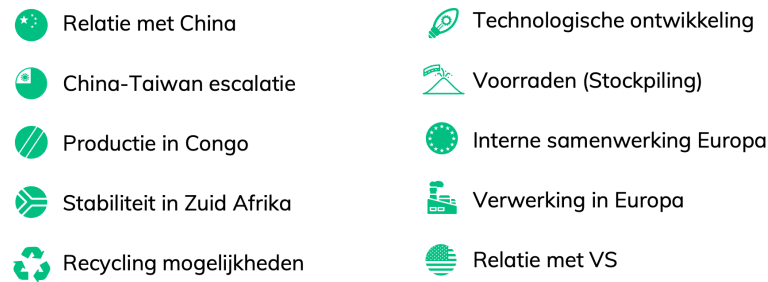
#### 3. **Clustering the driving forces and exploring cluster outcomes**

The driving forces were placed in an uncertainty-impact matrix, after which two major groupings could be formed; the internal innovation and cooperation in Europe, and the external relationship with China. Other drivers were not further explored due their relative low impact. For the investments and innovations in Europe, the worst case scenario sketched that even funds currently appointed to innovation is withdrawn and countries enter a free for all regarding the acquiring of materials. The best case scenario involves large investments in all parts of the CRM supply chain, including processing and recycling facilities. For Chinese cooperation, the worst case would be an export restriction on all materials processed and extracted in China. The best case scenario sees current export restrictions being withdrawn, and Chinese pressure on Taiwan reduced.

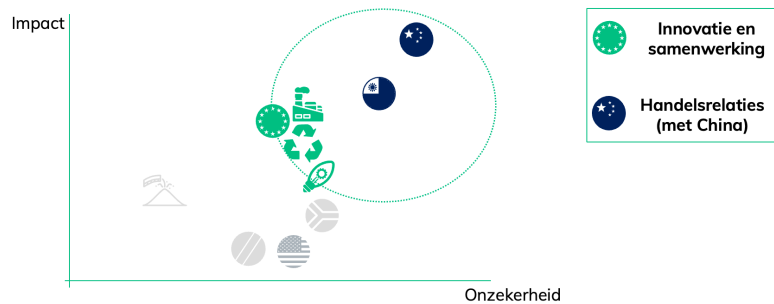
#### 4. **Framing the scenarios: Establishing a 2x2 matrix to outline four distinct scenarios.**

The matrix established has two axis, called 'cooperation and innovation', referring to the internal action regarding the sharing of knowledge and investments in innovations in Europe, and trade relations with China. The four distinct scenarios were listed as 'High innovation - High trade relationships', High-Low, etc.

#### 5. **Scoping the scenarios: Developing scenario narratives to describe the implications on CRM supply chains.**



**Figure 6.1:** The main risk uncertainties (in Dutch)



**Figure 6.2:** The impact-uncertainty matrix as presented in the SP workshop (in Dutch)

The effects from the extremes for both diver clusters were listed for each scenario. After this, interaction between the effects was sought. For instance, Chinese trade restrictions can initially increase prices of materials, which could be a driver for European innovation.

#### 6. Developing the scenarios: crafting detailed narratives with input from experts and stakeholders.

The outlines of the final scenarios were provided to an artificial language programme (Chat-GPT) which provided cohesive storylines. These storylines were critically examined and improved where deemed necessary in order to align with data found in SQ1 and increase relevance for company stakeholders. After this, the scenarios were discussed with business stakeholders from Copper8. Apart from that, all scenarios were discussed with a China trade expert from the Clingendael institute, a independent think tank. After these discussions final revisions to the scenarios were included. The final scenarios are attached in the Appendix E-K.

## 6.6. Conclusion

In this chapter, several tools applicable to increasing awareness in a business context have been introduced and compared. Scenario Planning has been found to be the most promising tool to meet the goals within the scope of this thesis research, as supported by the selection process described in this chapter. The SP method has been further analyzed, comparing various schools, approaches, and past implementations. This led to the construction of a framework for a more concise workshop format, which can be operated within 3 hours, for participants not previously familiar with the subject of CRM.

Having established a robust and theoretically-grounded framework for the communication tool, the next chapter will describe its execution and analyze its effects on participant awareness and sense of urgency. This analysis will not only answer SQ3, but will ultimately provide a direct, evidence-based answer to this research's guiding question: that a concise, narrative-driven scenario planning workshop is an effective communication tool for increasing risk awareness in companies.



## SQ3: What is the structure of the CRM awareness tool developed?

### 7.1. The CRM risk awareness workshop: a condensed scenario planning tool

Based on the analysis of communication methods and the theoretical basis of scenario planning, this research developed a specific intervention: The CRM Risk Awareness Workshop. As a condensed Scenario Planning workshop, the tool is designed as a practical and time-efficient mechanism to increase awareness and create a sense of urgency for CRM supply risks among participants who may not have prior knowledge of the topic.

The tool is structured in the following five modules:

1. Introduction: basis knowledge transfer
2. Scenario planning introduction
3. Scenario exploration
4. Strategy exploration
5. Summary and debrief

The schedule of the SP workshop as used in this thesis can be seen in Table 7.1. The remainder of this chapter will describe the contents of each of the modules in more detail.

#	Activity	Duration
1	Introduction – Introductions, personal experiences with disruptions	15 min
2	CRM fundamentals – What CRMs are and why they matter	20 min
3	Geopolitical events – Material geopolitics: past and present	20 min
4	Introduction scenario planning - Introduction method and planning	10 min
5	Defining key variables – Explaining major uncertainties shaping scenarios	15 min
6	Exploring future scenarios – Discussing 4 scenarios	20 min
7	Company-specific discussion – Assessing scenario impacts on your business	30 min
8	Strategy building – Identifying new strategic actions	30 min
9	Summary and debrief - Discussing the scenario worksheets	10 min
10	Evaluation - Discussing experiences and feedback of the workshop	10 min
<b>Total Duration</b>		<b>180 min</b>

**Table 7.1:** The workshop schedule as used during this research

### 7.1.1. Modules of the workshop

Introduction: base knowledge transfer (#1-3)

In order to interact with the scenarios effectively, it is important that all participants have at least a base level of knowledge of the risks discussed. In traditional SP, this is often provided by external experts who share their expertise on the various topics discussed. In this condensed format, the base knowledge transfer is provided through an introductory presentation at the start of the workshop. In 20-30 minutes, an introduction to CRM and geopolitics can be provided. This presentation can be standardised and does not have to be tailored to the organisation hosting the workshop, as it is important in AR that participants do not receive answers or direct help, but rather work towards these answers through discussions and cooperation (Bradbury et al., 2019).

The slides used for the introduction are provided in the Supplementary Material. In summary, the introduction consists of the following information:

CRM:

- Concepts in CRM (CRM, SRM, REE, Critical is not rare)
- What products contain CRM
- How is criticality determined (in the EU)
- Where are CRM extracted
- Difference between extraction and production
- ESG issues CRM

Geopolitics:

- Geopolitical risks according to HCSS (de Pooter et al., 2022)
- Development of China
- CRM in geopolitical trade wars
- Reasons EU does not produce many materials
- Mitigation strategies (CRMA and Dutch material strategy)

Scenario planning introduction (#4)

The SP methodology is briefly introduced, both to give the tool some theoretical backing and to provide participants with the structure of the second half of the workshop. The historical background from

SP at Shell and the American military is mentioned, as well as the fact that the tool is quite renowned in management strategising. The steps of the SP workshop are introduced as follows:

- Defining uncertainties – Identifying key uncertainties that shape future scenarios
- Exploring scenarios – Discussing possible combinations and directions of most important uncertainties
- Company-specific discussion – Assessing the impact of these scenarios on your organization
- Risk mitigation strategies – Evaluating existing precautionary measures and identifying new ones

#### Scenario exploration (#5-7)

The scenario exploration consists of two phases; the construction of the scenarios and the discussion of the scenarios. The first phase is the most condensed part compared to traditional SP, as instead of interactively discussing uncertainty variables and choosing the most important variables as a group, this has been carried out in advance by the facilitator. As it is often mentioned in SP theory that discussion and understanding of the risks is essential to build ownership and participation in the scenarios, it is important to ensure that all participants understand the risks and their impacts. Therefore, risks will be introduced one by one, explaining why they impact CRM supply and what the uncertainty is regarding the specific risk.

The second step is the explanation of the placement of the risks in the impact-uncertainty matrix. Then it is explained how the risks are grouped and what the two main axes are. Then the four scenarios are introduced one by one. The text of Appendices E-K can be used to communicate the scenarios more realistically. An AI-generated image is used to facilitate the recall and distinction of the scenarios, except that no data or media are used according to the SP theory as described in Bradfield et al. (2005).

The discussion about the scenarios is then led by the facilitator with the aim of starting a lively discussion about the scenarios. It is important that the discussion does not drift towards the question of which scenario is the most realistic or likely, but rather about the possible impacts of the scenarios on the company and its operations. After discussion of the scenarios in the group, the participants are divided among the scenarios, after which people fill in the first column of the worksheet, as depicted in the Appendix L. The effects will be discussed in plenary, after which the second column is filled in, in which the participants describe how the possible risks can be mitigated and benefits can be enforced. The results of this discussion are written on large paper or whiteboard.

#### Strategy exploration (#8)

What follows is a discussion of the different strategies that the company can implement. The facilitator should lead the discussion towards finding the actions which are mentioned multiple times across different scenarios, or would be fitting in more than one scenario. This indicates that whatever happens, the strategy would be positive for the company and should therefore be considered to implement. From this discussion, a limited number of strategies should be chosen. Preferably, participants with different functions within the company work together on a single worksheet, filling in the backside, Appendix M.

#### Summary and debrief (#9-10)

The different strategies are discussed on viability for the company. This also allows other participants to give their input on who should be contacted, what the preferred timelines are, and decide who will be responsible for each of the strategies. At the end of the workshop the results of the session and the change in awareness and sense of urgency of the topic can be discussed with participants.

### 7.1.2. Facilitator guidelines

During the SP workshop, the facilitator and the participants must follow several guidelines to improve the productivity of the workshop, as well as uniformity and comparability between different workshops. These are adapted from Cairns and Wright (2017) and complemented with advice from professional workshop facilitators and personal experience.

#### Provide general information, no answers

One of the key differences between an SP-workshop and a lecture is that participants have to actively participate and think critically to come up with their own analysis. This is in line with the principles of AR, which state that the facilitator does not help the participants, but rather cooperates with them.

Therefore, it is essential that the information provided in the introduction is not tailored to the specific company participating. If participants do not know what materials are in their products, this can be a key

outcome of the workshop. In addition, avoiding providing company-specific information makes the tool more scalable and less time-intensive for the facilitator.

#### Equal participation

A round-robin methodology is used to ensure that all participants have the opportunity to speak. For each topic, members of the group share their perspectives in turn, with the starting point systematically rotated to prevent any individual from dominating the conversation.

#### Focus on clarification, not debate

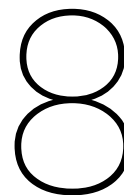
During the initial sharing phase, dialogue is limited strictly to clarification questions to ensure that all viewpoints can be fully expressed without premature debate. This encourages a deeper exploration of initial thoughts (e.g., *'Why do you believe that would happen?'*) rather than immediate judgment.

#### Embracing divergent thinking

A core pillar of SP is the active encouragement of intellectual conflict and the acceptance of various outcomes, whether this consensus, fragmented viewpoints, or a clear majority opinion. Consequently, no idea can be dismissed or challenged as 'wrong' unless it could be proven so beyond doubt and with unanimous agreement of the group.

#### Recording of viewpoints

All generated viewpoints are recorded and written down to ensure that the broadest range of possibilities is captured for subsequent consideration and analysis.



# Results from the intervention

## 8.1. Introduction

This chapter presents the findings from the Action Research cycles conducted to evaluate the effectiveness of the SP workshop, the communication tool introduced in SQ2 and outlined in SQ 3, Chapter 6 and 7 respectively. The results are based on quantitative results from pre-and post workshop questionnaire filled in by participants, as well as qualitative questions, interviews, observations, and participant responses gathered during and after the tool's implementation. These findings inform the extent to which the tool influenced awareness, urgency, and strategic responses to Critical Raw Material (CRM) risks within participating organisations.

The results demonstrate a shift in participants' perception of Critical Raw Material (CRM) risks. Although the quantitative data from the questionnaires showed only modest changes, the qualitative findings of the interviews and workshop discussions revealed a significant increase in both the perceived relevance of CRM risks and the perceived urgency to address them. In addition, direct support for the implementation of mitigating strategic action was expressed. The following sections will detail these findings, starting with the pilot study and then moving on to the main workshop results. Finally, feedback related to the workshop will be presented, which will be evaluated to understand the acceptance of the tool as a communication implementation in business contexts.

## 8.2. Pilot

The workshop has been conducted as a pilot among business professionals working at Copper8, as described in 4.2. There were seven participants, of whom six have completed both the pre- and post-workshop questionnaire. The results of these questionnaires will be presented in a concise way.

### 8.2.1. Pre- and post-workshop questionnaire

#### Awareness and understanding

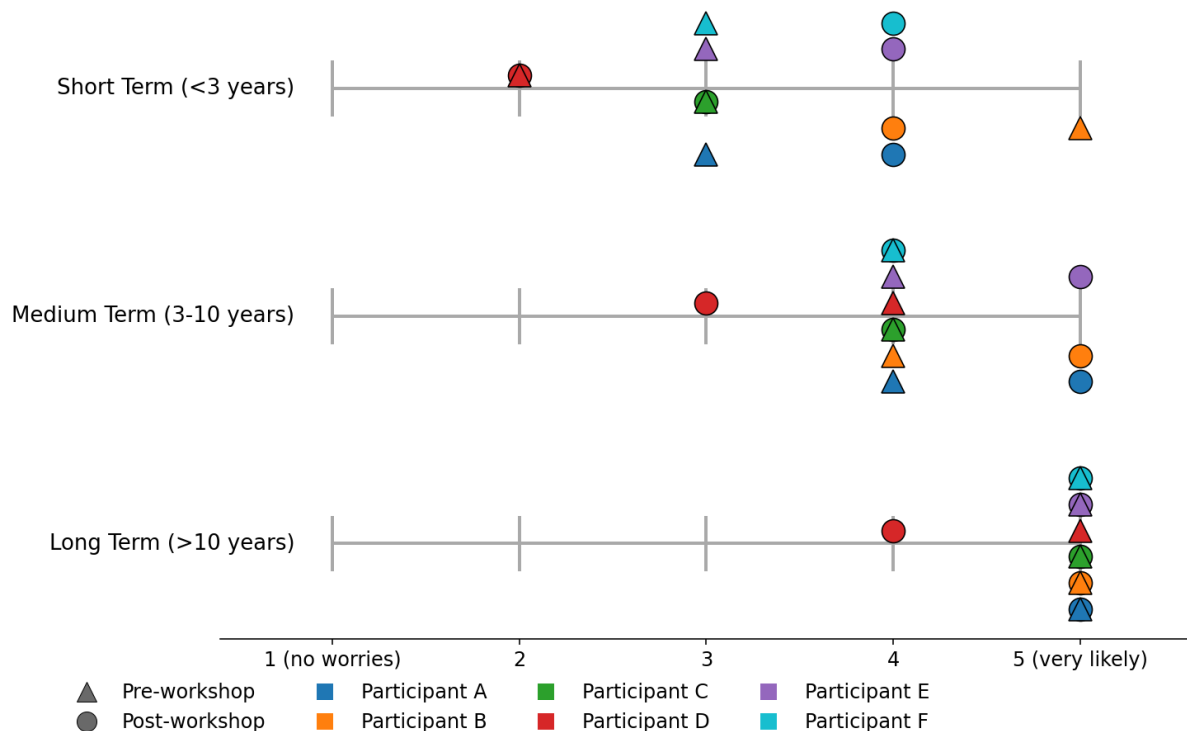
Results from the pre-workshop questionnaire show that most participants only had a superficial understanding of the term 'Critical Raw Materials', as 5 of the participants indicated they knew the term but did not know which materials the term entailed. Only one participant said that they knew which materials the term entailed. Three of the participants had previously considered CRM in their work activities, although never in raw form but as part of components companies bought from other suppliers.

#### Sense of Urgency

All participants felt that CRM supply would be an issue for companies in the coming years. In the next three years, the average risk estimate was 3.5/5, in which the scale was indicated from 1 (very unlikely) to 5 (almost certainly). Between 3-10 years, the risk was assessed as 3.9/5, while in the long term, the risk was estimated to be very likely by all participants. This shows that long-term CRM supply was seen as more problematic than short-term supply.

In figure 8.1 the difference in risk perception between the pre- and post-workshop questionnaires can be seen for individual participants. It is visible that for most participants the perceived likelihood that CRM supply risk is a problem for their company in the short term is elevated after the workshop. The same

result is visible for the medium term. For the long term, five participants remain at the highest likelihood, while one participant felt it is likely.



**Figure 8.1:** Perceived likelihood of critical material supply risks across different time horizons before and after the workshop.

The question about the specific risks CRM poses in the next five years showed a general awareness of CRM risk categories. All participants felt dependence on specific countries was problematic for companies, while geopolitical tensions, ecological impact, and social implications were also mentioned as urgent/problematic by five of the participants. Fewer participants deemed supplier dependence, shortages due to increased demand, and limited natural stocks problematic, 4, 4, and 3 respondents rated these topics problematic, respectively. After the workshop, there were more risks that were considered urgent / problematic than before. Natural depletion was selected as problematic by fewer participants than before the workshop.

When comparing CRM supply uncertainty with other strategic risks, net congestion and economic recession were considered more important by most participants, with only one participant choosing CRM supply risks as more important. AI was estimated to be of similar importance, while CRM supply risks were deemed of more importance than employee shortages and environmental legislation by a majority of the participants.

#### Scenario planning experience

None of the participants had participated in a Scenario Planning workshop before. However, all participants indicated that they think about the future a lot.

The workshop was divided into the following parts: Introduction CRM, Introduction geopolitical situation, Discussion of future scenarios, Writing down risks and chances of scenarios, and Construction and discussion mitigation strategies. The participants had to rank the different parts of the workshop from the most to the least contributing to a gain in the sense of urgency. Four participants rated 'Writing down risks and chances of scenarios' as most contributing. Two others rated the 'Introduction geopolitical situation' as primary supporting part.

As all professionals are consultants, the pilot provided an opportunity to gain insight into how they viewed using scenario planning in their work. Rating whether they would apply scenario planning in

consulting projects with clients to increase risk awareness, 2 participants strongly agreed, while the other 4 participants agreed.

After the workshop, the participants showed a good understanding of the SP goals. In answering 'Is there something specific that you took away from the workshop?', responses showed a deep understanding of the concept of scenario planning, such as: "That there can be different strategies for a changing world, but that there are also a number of actions that make sense in all scenarios" and "How scenario planning doesn't focus on the most likely outcomes, but rather ensures you're prepared for unexpected situations". Other participants focused on the risk knowledge they gained: "The renewed realization that China holds such a powerful position in this area" and "The number of uncertain factors, and how insignificant the Netherlands is on the global stage regarding this topic" and "The knowledge about dependence on China, particularly in processing".

### 8.2.2. AR feedback cycle

One of the pillars of AR is the participatory evaluation cycles, with adjustments to the research format as results. Therefore, the outcomes of the participatory discussions and feedback will be presented in this section as results. The consultants participating in the workshop are a suitable group to participate in the evaluation process, as they can be viewed as practical experts, being familiar with facilitating workshops at companies.

#### Participatory discussions

Participants were observed to be very involved during the workshop. The knowledge from the introduction was shown to be applied in the discussion of the risks and opportunities of the scenarios. Recommendations and points of critique were discussed and later implemented in the introduction narrative. The scenario's were found cohesive, and allowed for interactive discussion of possible CRM supply risks. After the workshop, participants were asked whether they felt that the workshop encouraged changes or implementation in business operations. All participants who responded to the question saw potential in the format. There were two main points of feedback on the pilot: the lack of a clear structure during the SP part reduced the concreteness of ideas that participants would take away from the session, and awareness from the facilitator is necessary to avoid participants leaving with the feeling that the complex topic is outside of their sphere of influence.

#### Questionnaires

There were some questions in the questionnaires that provided multi-interpretable answers to the concepts. Therefore, it was decided to change the following questions: 2. In hoeverre ben je bekend met de term 'Critical Raw Materials'? (How familiar are you with the term "Critical Raw Materials" was changed from a multiple choice question to 4 statements with Likert scales. This allowed a better understanding of the different elements combined in the initial question.

For question 4 (Hoe groot schat je de kans dat de aanvoer van CRM voor bedrijven een probleem wordt ...) the likert scale was changed. Initially, it went from 1 (no worries) to 5 (almost certainly). The participants remarked accurately that the scale measures two different concepts, the emotional perception of risk (state of worry) and the subjective perception of risk (certainty). The new scale measures the subjective perception of risk, ranging from 1 (no chance) to 5 (certainly).

Question 5 was changed for the same reason; it asked about a problem / urgent within 5 years. This was changed to questioning whether the participants viewed the issues as problematic for their company, focusing on the concept of awareness. In the interview, it was checked why risks were seen as 'not problematic' if this was filled in. Also, the answering model was changed from checking the boxes to Likert scales. The first version of the questionnaire did not allow one to assess whether awareness of risks increased. Apart from that, checking boxes without explanation could result in a bias where participants do not want to seem ignorant and therefore check any of the boxes that seem relevant without actually understanding the underlying risks. Also, the time scope was changed from 5 to 3 years to better align with the perception of 'short-term' used in the workshop and the rest of the thesis.

Question 7 'Can you rank the following risks from most to least urgent for your company?' was added to check whether participants had understood question 6, as during test runs people expressed being confused by the way question 6 was asked, as they did not understand to which concept the relativity was measured.

### Worksheet

To create more structure, a worksheet was designed which is to be provided to participants during the interactive part of the SP workshop. The worksheet consists of a front and a back. The front-side spaces for filling in the risks and opportunities resulting from their chosen scenario in their company. After that, they have to list how the company could mitigate risks and take advantage of opportunities. The backside contains a framework that facilitates the introduction of a strategic measure. It is filled in with what questions still remain, who has to be contacted, and how the timeline of the implementation would look like. The final worksheet is attached in Appendix L.

## 8.3. The workshop

### 8.3.1. Pre-workshop questionnaires (PWQ) and interview (INT)

The following section lists the information per sub-concept. As described in the methodology, the information from the PWQ has been allocated according to the questionnaire conceptualization, which is attached in Appendix C, while the interviews were transcribed and coded. For each sub-concept, the findings from the PWQ are in the top paragraph, findings from the interviews in the bottom paragraph.

#### Awareness (Pre-Workshop Evaluation)

##### **AW1 – Material familiarity**

The pre-workshop evaluation indicated mixed levels of (specific) CRM familiarity. While all participants confirmed the presence of CRMs in their company's value chain (Q3), only two stated they knew which specific CRMs were relevant for their organisation's products (Q2b). The other two participants indicated they did not possess this specific knowledge.

(INT) From the interviews, it was found that there was a foundational awareness of CRMs among participants, ranging from general knowledge of CRMs to understanding its contents in purchased components. Various material examples such as silicium in PV panels and gold and "various strange metals" in processors were mentioned, although the various strange metals could not be listed. Among most participants there was an understanding of criticality; for instance, China's 80-90% market share in certain battery materials is mentioned as driver for supply risk. Some participants noted changes in the EU CRM list, such as copper's addition 3 years ago, showing an understanding of criticality assessments. Some aspects of criticality mentioned are not completely consistent with literature. One of the participants mentions that copper cannot be a CRM as it is currently so widely available.

##### **AW2 - Element-Product Link**

The link between CRMs and specific products was partially understood. All participants acknowledged CRMs are in their value chain (Q3), and all state this is contained in purchased products of suppliers. However, as noted under AW1, only half of the participants felt they knew which CRMs were relevant for the products within their organisation (Q2b), suggesting that while the general presence is known, the explicit element-product link for all relevant CRMs is probably not there.

(INT) The link between CRMs, and the products and components necessary for company operation is clearly recognized. Asked about what they think of when they think of CRM, all participants mentioned "components in the items we buy", and many different appliances were named: materials in IoT devices, heat pumps, control system components, processors, sensors, PLCs, servers, heavy magnetic materials. There is a clear awareness that the company handles "many composite materials" containing "all sorts of different materials". It is mentioned that it's mostly raw materials in their components, not stuff they buy themselves

##### **AW3 - Risk Understanding**

There was a stated understanding of CRM-associated risks, with all four participants stating they understood these risks (Q2a) and had encountered CRM-related risks in their work (Q2c). Specific risk understanding (Q5) highlighted concerns around 'Dependence on specific countries' (Q5c) and 'Geopolitical tensions' (Q5h) which were rated 'very problematic' or 'problematic' by all four. 'Price volatility' (Q5g) was also a significant concern for three of the four respondents. In contrast, 'Dependence on specific suppliers' (Q5d) saw mixed responses, with two finding it 'problematic' and two 'not problematic.'

(INT) There is an evident understanding of geopolitical and logistical supply risks associated with CRMs.



Risks from China (e.g., export restrictions, market control) and logistical disruptions (e.g., Suez Canal blockage, shipping diversions described as the "biggest risk") are well understood. Past instances of hardware unavailability, such as for specific PLCs due to hoarding which led to price hikes ("Where they initially got them for a few hundred bucks apiece, we then had to pay many thousands of euros"), illustrate practical risk comprehension. Similar future risks concerning material availability are anticipated ("I expect that mechanism in ten years as well... regarding material availability"). Apart from that, participants acknowledge the risk that magnets are only produced in China now, with no other country having the infrastructure to do so.

#### **AW4 - Relevance of CRM Risk to organisation**

The relevance of CRM risk to the organisation was affirmed by all participants having encountered such risks (Q2c). The evaluation of specific risks (Q5) as problems for the company in the next three years were in line with these answers, as geopolitical and market-driven risks (e.g., 'Tekorten door toenemende vraag' (Q5e)) were seen as relevant. However, the direct organisational relevance of 'Ecological impact' (Q5a) and 'Social impacts' (Q5b) was perceived more variably by the participants who responded to these sub-questions, with most participants being neutral towards these risks.

(INT) The relevance of CRM risk is primarily framed by its potential for operational disruption and impact on projects and customers. The company has experienced problems in the past; due to unavailability of components, projects were stalled, making this "our biggest risk". Previous unavailability of a single controller part for heat pumps due to supply chain disruptions illustrates this direct relevance. Global tensions are mentioned as a specific risk for the company. Internal experts conduct risk assessments, and significant dependence on China is acknowledged. One of the participants saw dependency on China as a "very big" risk to their division and believed that CRM awareness is changing the procurement landscape beyond just price. A participant clearly articulated that "if parts are really no longer there, it can simply mean that it no longer functions", thus impacting the "viability of your business" ("bestaansrecht"). Not all risks are seen as this dire. It was frequently expressed that price volatility would not really be a problem as long as they could transfer this increase to their customers.

#### **AW5 - Solution Awareness**

The questionnaire did not ask about solution awareness, as it is unknown whether participants even understand the topic of CRM.

(INT) Some raw material demand reducing solutions, such as circular design or take-back agreements, are mentioned. Other participants stressed the importance of dual-sourcing approaches and long-term contracts with suppliers.

#### **AW6 - Understanding Social Sustainability**

Two of the three participants who responded to Q5b ('Sociale omstandigheden') identified these as 'problematic' for their company. One participant rated this as 'Neutral'. This points to a partial recognition of the direct organisational relevance of CRM-linked social sustainability aspects.

(INT) Social sustainability aspects of CRMs, such as labor conditions and sourcing from specific regions, are acknowledged. One participant mentioned sourcing solar panels from "Uyghur regions" as problematic and contractual clauses against "child labor or low-cost labor". A participant briefly mentioned that "material and health are going to intersect more and more".

#### **AW7 - Understanding Environmental Sustainability**

Just one of the three participants who responded to Q5a ('Ecological impact') considered it 'problematic' for the company. Two participants rated it 'Neutral'. This suggests a varied awareness of the direct short-term organisational problems posed by environmental sustainability issues linked to CRMs.

(INT) In general, the insights into the environmental aspects of CRM were low. It was explained that due to the nature of their operations, their current way of looking at impact was strictly focussed at downstream effects, with a strong focus on energy efficiency. It is mentioned that for infrastructural projects the emissions of large material groups such as steel and concrete are taken into consideration, such calculations had not been made for other materials and products. While circularity initiatives were mentioned, this was mostly to emphasize the barriers due to financial and practical limitations.

### **AW8 - Understanding Circularity Aspects**

The pre-workshop questionnaire did not include questions that directly assessed participants' awareness or understanding of circularity as a key issue or solution strategy related to CRMs, similar to AW5.

(INT) Participants mention several circularity initiatives currently undertaken as part of their ESG initiatives. However, many of these are not CRM related, e.g. about the reuse of wood and packaging materials. Interestingly, one of the participants mentions that recycling forms an obstacle to material tracing, as a material containing 30% mixed contents is impossible to track down to the country of origin. A driving factor for circularity could be pressure from customers, as it is mentioned that people in projects are reluctant to throw things away. Currently, recycling of products is considered unviable, as labour costs are too high compared to relatively low material costs. In addition to that, guarantee and customer experience are prioritized over environmental aspects of circularity. Lastly, an often mentioned point is that only a small part of emissions and impact results from production and material use, with most impact being made during the years the product is used by customers.

### **AW9 - Blackspot Awareness**

The questionnaire did not directly probe for awareness of "unknown unknowns" or blackspots in CRM supply chains. However, the responses to Q3 regarding influence over suppliers (two participants felt they had "geen invloed" (no influence) over suppliers of products containing CRMs) might indirectly suggest an awareness of limited visibility or control, which can contribute to blackspots.

(INT) Participants acknowledged the blackspots in their supply chain, mostly in relation to knowledge about the contents of their products. When suppliers are asked about material origins, the response is often "we cannot disclose that, or we don't know a percentage". A participant described obtaining detailed composition/footprint from manufacturers for components from China as a "monstrous task", while another stated that CRMs were a "very intangible subject for us".

### **AW10 - Observation of a Changing Environment**

Participants generally anticipated that CRM supply would become more problematic over time. For the short term (<3 years, Q4a), two saw a 'small chance' while two deemed it 'more probable than not'. For the medium term (3-10 years, Q4b), this shifted to '50/50' (two participants), 'More probable than not' (one), and 'Certainly' (one). For the long term (>10 years, Q4c), all anticipated problems, with two rating it 'Certainly' and two 'More probable than not.' 'Shortages due to rising demand (Q5e) were also considered problematic by three of the four participants.

(INT) Future risks concerning material availability are anticipated, as people expect challenges to material availability in 10 years. Also, the dynamic nature of the CRM landscape is recognized. Due to IoT, and the "emerging" trend of increased sensor use, material demand is expected to increase, and people observed that purchasers now consider "more dimensions" beyond just price. The evolving EU CRM list is mentioned, with participants anticipating changes in the future lists. Apart from that, participants expect the procurement process to change, as it has already shifted from just pricing to including CO2, and it might also include critical materials in the future.

SU - Sense of Urgency (Pre-Workshop Evaluation)

#### **SU1 - Prioritizing Risks**

CRM supply risks were generally ranked lower when compared to other strategic concerns (Q6). For instance, 'Personeelstekort' (Staff shortage) was rated 'more important' or 'way more important' by all four participants. 'Changing market demand' was also consistently seen as more important. In the direct ranking (Q7), 'CRM supply risk' was ranked first by only one participant, while others placed it fifth or sixth.

(INT) CRM risks are typically prioritized below immediate client needs (like energy efficiency) or cost. When considering critical materials, most participants strongly favored a "risk perspective" over a "sustainability perspective". Just one participant mentioned the ESG aspects of CRM being important to simply frame CRM as a supply risk problem. The core sentiment across interviews is that the urgency for CRMs is driven by direct business impacts like project delays rather than by sustainability concerns.

#### **SU2 - Perceived Sense of Closeness**

The perceived closeness of CRM supply was measured by asking whether participants saw this becoming a problem in the short term (<3 years, Q4a), with responses divided between a 'small chance' (two participants) and 'more likely than not' (two participants). The sense of closeness increased for the

medium term (3-10 years, Q4b), with no participant rating it less than '50/50.' This suggests an emerging, rather than immediately pressing, sense of closeness for most.

(INT) While the participants acknowledge that CRM might be a problem for them, none of the participants mentioned the pressure to act now. They expressed interest in better understanding the problem, rather than feeling that it would be best to act as soon as possible. The issue was not really felt in their surroundings, and participating in the workshop would make them frontrunners in this topic.

### **SU3 - Pressure to Act**

The pre-workshop questionnaire did not directly inquire about external or internal pressures.

(INT) External pressure stems mainly from regulations (CSRD, Scope 3) and sometimes specific client demands. Participants anticipated increased circularity requirements from government and clients, like Schiphol's request for a Building Circularity Index. However, it was expressed that the company had never received any CRM-related questions, revealing low external pressure on the topic. One of the participants states that the ESG related factors of CRM are important enough to act on the topic, as he would always want a better world.

### **SU4 - Seeing Opportunities**

The perspective on reducing CRMs (Q10) was divided, suggesting mixed views on opportunities. Two participants saw it as an important area for strategic development or current activity, however, this does not differentiate whether this is driven by opportunity or risk mitigation. The other two focused on negative aspects like profitability ("not viable") or difficulty ("too difficult for the benefits"), indicating they did not currently perceive it as an opportunity.

(INT) Opportunities are primarily seen in leveraging CRMs for financial gain or market differentiation. One participant stated, "I strongly believe that if you do this well as a company, it will make you money". However, the participant also pointed out that initiatives lacking clear financial incentives or subsidies, such as creating a material reuse library, are unlikely if they require significant upfront investment without client support, or "if that's not a subsidy, then nobody will do it". While participants saw an opportunity to "contribute" to developing responsible material solutions, they noted market barriers. One of the side benefits of having more knowledge of the material contents is mentioned to be that Scope-3 emissions could be completed.

### **SU5 - Willingness to Act Immediately**

Taking a look at Q10, two participants indicated a readiness or ongoing effort towards CRM reduction, with one keen to "develop a strategy as soon as possible". The other two participants did not express willingness based on their responses concerning the feasibility of CRM reduction.

(INT) There is a general willingness to improve knowledge. Participants explained that before knowing what the risk entailed and what the relevance was, they did not know whether action would be necessary or not.

## **ST - Organisational Strategy**

### **ST1 - Material Assessment**

The questionnaire did not directly ask about specific organisational steps taken for material assessment.

(INT) Participants state that although initial efforts have been made to identify information on specific materials in their value chain, contact with suppliers has proven an obstacle. Apart from that, it is mentioned that the company has thousands of suppliers, making it very difficult to request information and handle the information if provided. Material passports are not yet standard in the industry, and it is mentioned that the company is not very far along with a CRMA type strategy yet.

### **ST2 - CRM-Specific Strategies**

The existence and practical application of CRM-specific strategies varied. In Q8 two participants indicated their organisations had related policies, one on "sustainability" and another on both sustainability and "supply security". However, for one of these, the policy reportedly had "no practical application" in procurement or use (Q9). The other reported the policy had influence on design/procurement. The remaining two participants stated "There is no policy". Preparedness for disruptions (Q11) was generally neutral to unprepared, further suggesting limited existing strategies. Participants answering Q10 (regarding the reduction of CRMs in the value chain) with 'we are already working on this' were asked specifically what solutions were currently in place during the interviews.

(INT) Strategies like dual sourcing and long-term partnerships are employed to ensure supply continuity. Especially the effectiveness of long-term partnerships is emphasized, telling how this has helped the company during supply disruptions in the past in requiring materials while other companies could not. On the other hand, it is stressed that there is currently no CRM specific policy in place.

### **ST3 - Prioritization of Materials**

The pre-workshop questionnaire did not include questions about whether the organisations prioritize certain CRMs over others in their strategic planning or risk management efforts.

(INT) Some participants mentioned that they would like to know on which parts or materials the company could make the most impact. However, most participants did not mention the concept of prioritization between materials.

### **ST4 - Proactive vs. Reactive Stance**

The organisation's stance, inferred from preparedness (Q11), appeared largely neutral or reactive. While one participant felt "well prepared" for sudden disruptions (Q11a), overall preparedness for disruptions, long-term shortages, and price volatility was mostly "neutral" or "unprepared"/"very unprepared". One participant showed a proactive stance, wanting to "develop strategy as soon as possible" (Q10) and another's statement "Already working on the issue" (Q10) suggests some proactive action in specific individual contexts regarding CRM reduction, although this contrasts with other perceptions and findings.

(INT) The company aims for proactivity in areas like CSRD reporting, but many CRM actions are reactive. It is mentioned that if there is no paying client, it is unlikely there will be action from the company to change current policy. The lack of engagement from their broader "industry association" ("branchevereniging") indicates a more reactive sector. It is mentioned that "if something is not mandatory, the company will not do it", showing a clear reactive stance.

### **ST5 - Comparison with other Organisations**

The pre-workshop questionnaire asked participants to compare their organisation's CRM strategy, preparedness, or awareness with other organisations in their sector or beyond.

(INT) Comparisons are made internally and externally, showing that participants often benchmark their performance against others. The participants compared the amount of legislation and research with their previous companies, other business units, and the entire branch. Some of the comparisons are positive, e.g., participants thinking their company is a frontrunner in the field of CSRD footprint reporting, and negative; e.g. material take back systems other companies implemented would not work within our company. Most participants feel that CRM risk is a lot more relevant for them than for other companies, e.g., infrastructure companies handling mostly concrete and steel. Suggestions are made for looking to "industry peers" for CRM solutions.

Communication Tool Acceptance (CT)

CT - Communication Tool Acceptance (Pre-Workshop Evaluation)

#### **CT1 - Perceived usefulness (of the workshop)**

The pre-workshop evaluation (Q12) revealed clear expectations regarding the workshop's utility among the three participants who responded to this question. Participants hoped the workshop would serve to clarify the urgency of CRM issues and assist in setting the internal agenda (e.g. how urgent this problem is and how we can put it on the internal agenda). Furthermore, there was an expressed desire for "A better insight into the problem". One participant specifically hoped to "Gain insight into risks for their company. Awareness in the business. First actions". These expectations collectively point to a perceived usefulness if the workshop can be used as a means to deepen understanding, increase the sense of urgency, and identify actionable steps.

#### **CT2 - Perceived ease of use**

This sub-concept was not assessed in the pre-workshop questionnaire, as it can only be judged after the workshop.

### **8.3.2. Worksheets**

During the workshop, the first step of the scenario planning tool involves the individual listing of risks and opportunities associated with the different scenarios. For the 'negative' scenarios, where innovation

and/or trade with China were impeded, the main risks mentioned were problems in product and material supply. The participants mentioned that this would make them unable to supply the necessary appliances to the customers. Some participants thought that this would only prolong delivery times and cause price spikes, while others were worried that supply would shut down completely.

There were several opportunities listed for each scenario. Some of these matched the literature, while others provided new insights. This will be further discussed in the discussion. Traditional supply chain risk mitigating ideas included increasing stocks and tightening contractual obligations for suppliers. In addition, it was suggested to directly contact suppliers in China instead of having intermediaries.

The participants also saw opportunities in the negative scenarios. They argued that under pressure the company would adapt more quickly, leading to forced choices in the favour of innovation.

Working together in the sector was seen both as an opportunity and as a possible risk due to the exchange of knowledge. Although this was generally seen favourable for better mitigate large risks, such as incomplete material unavailability, losing ownership of knowledge was seen as an immediate risk to the companies' competitive advantage.

Several of the ideas written down refer to external cooperation, e.g. with knowledge institutes or universities.

#### Strategies

At last, the participants were asked to fill in the strategy worksheet, as provided in L, in pairs. The chosen strategies were 'Insight into CRM as organisational and production risk' and 'Coalition.'

Insight into CRM as organisational and production risk clearly relates to ST1. The goal of the strategy is stated as 'where is it going to hit us \_first and \_hardest. Questions to be answered for that strategy include which 10 products are most at risk due to CRM content, where disruptions would hit the company, and if a timeline considering the 'scarcity' of these products could be made. These questions relate to multiple sub-concepts, most prominently ST3, AW4, and AW2.

The other strategy was named the "formation of coalitions". The questions to answer for this strategy were; for which products strategies are currently in place in and out of the Netherlands, and what the company would have to offer in a coalition.

The first steps to be taken were increasing the internal urgency, performing a stakeholder analysis, and forming teams out of the company, e.g., with government organisations.

#### 8.3.3. Observations

As stated in the methodology, the last half hour of the workshop was dedicated to discussing the topic of CRM, the proposed mitigation actions, and feedback on the workshop. This can be seen as a focus group, as the four participants went into active discussion with the facilitator regarding the topics. This discussion has been transcribed, and will be presented here combined with the observations from the workshop and the worksheets, which were filled in by the participants and discussed in the group. The results from the worksheets were summarized on a whiteboard during the workshop. They are added to the annex P

#### 8.3.4. Post-workshop questionnaires (PoWQ)

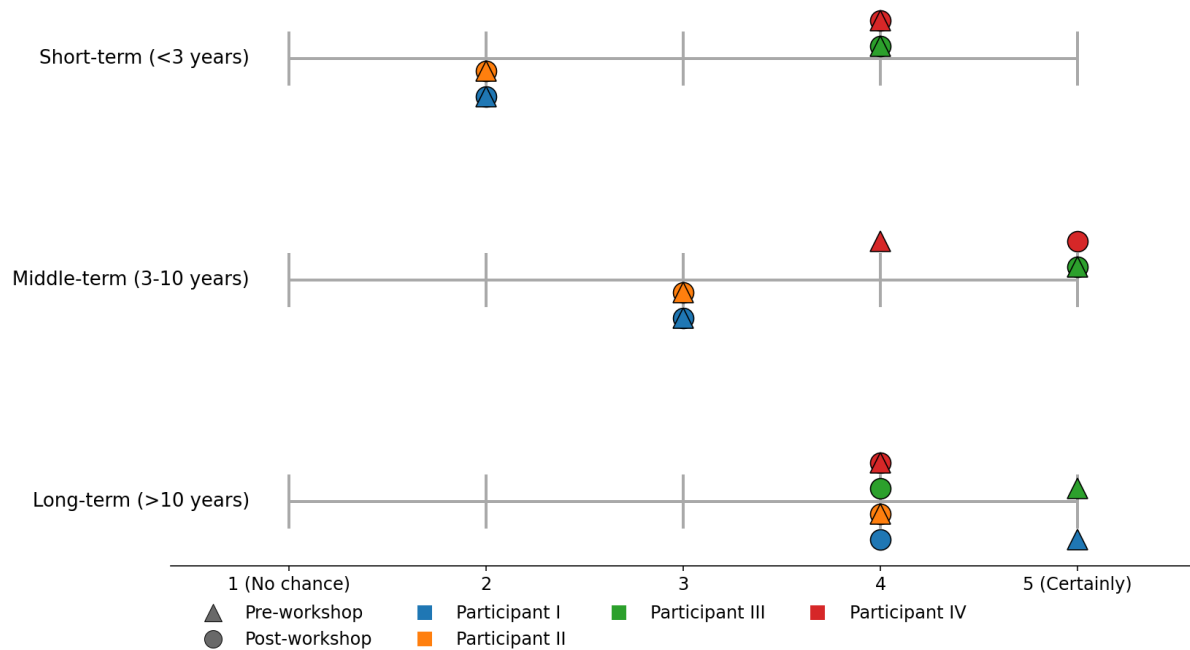
The PoWQ are similar to the pre-workshop questionnaires and will be used to compare results.

##### CRM as a problem to the company

As visible in Figure 8.2, most of the participants rated the question of whether CRM would be a problem for their company similarly before and after the workshop. It is visible that there is little change between the pre- and post-workshop responses. Long term impacts on the company are deemed less likely by two of the participants, and one participant thinks middle-term risks are more certainly having an impact.

##### Different risk factors to the company

Table 8.1 shows the difference between the responses before and after the workshop to the risk categories, which participants were able to rate according to how problematic they thought this risk would be for their company. The 5-point Likert scale has been quantified, so 1 means the problem is rated 1 step more problematic, e.g. from neutral to problematic, -1 one step less problematic, e.g. not problematic to totally not problematic.



**Figure 8.2:** Perceived likelihood critical material supply will be a problem across different time horizons, before and after the workshop.

	Ecologic	Social	Countries	Specific suppliers	In-creased demand	Limited stocks	Price volatility	Geo-political tensions
A	0	0	0	0	0	-2	0	0
B	0	1	0	0	0	0	1	0
C	-1	-1	0	1	-1	-1	0	1
D	0	0	-1	0	0	1	0	0

**Table 8.1:** Change in perceived urgency of CRM-related risks per participant

#### CRM related risks

Results from these questions are mixed. Market demand is rated less important relative to CRM supply risks after the workshop than before. AI and personnel shortage are relatively more important for some, while less important for others. This is also visible in the ranking question, where for one participant, CRM went from sixth to third rank, for one, it remained in fifth place, and for one it moved from fifth to sixth rank. One participant did not fill in these questions and could thus not be included in the analysis.

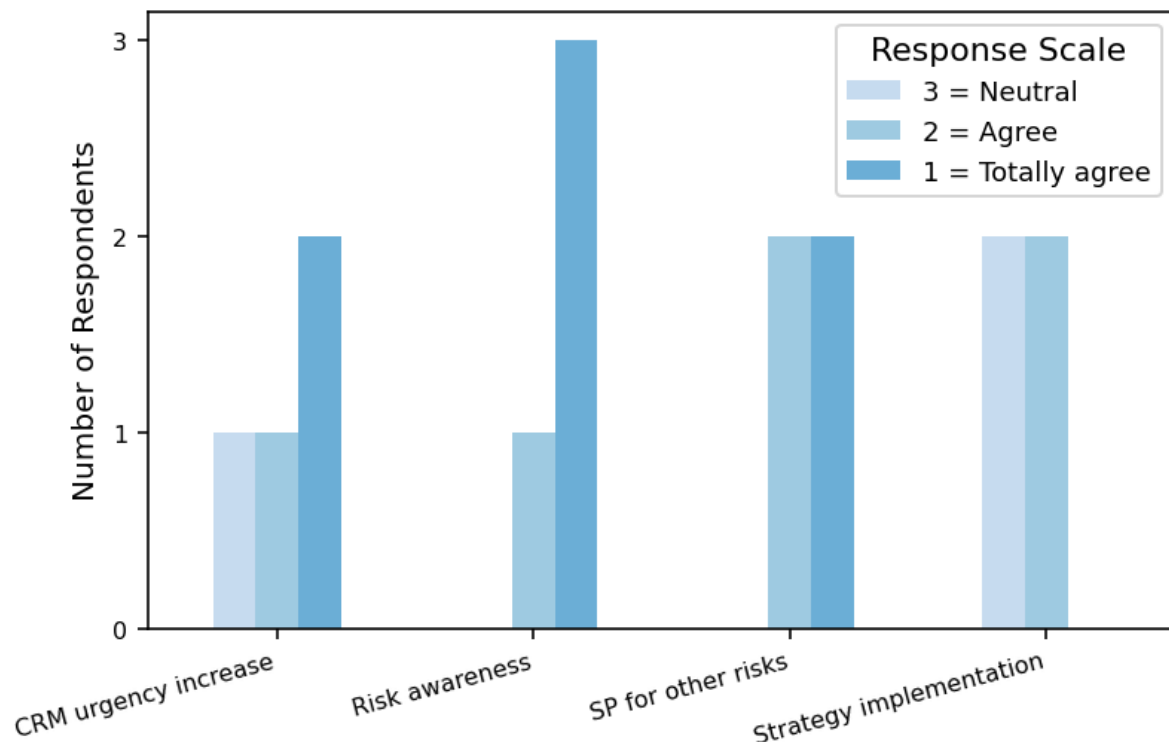
Comparing the pre- and post-workshop results on specific risks as a problem with the company shows a similar mixed outcome, with perceived risks remaining similar on average. The highest rated risk is dependence of specific countries, which scores an average of 4.5 before and 4.75 after the workshop. Limited natural supplies increase by 0.5, ecological impact and rising demand increase by 0.25, social risks remain similar, and price volatility and geo-political tensions drop by 0.25.

#### 8.3.5. Workshop effectiveness

This section will synthesize findings beyond the sub-concept level analyzed in previous chapters by structuring the concepts in themes, as prescribed in the methodological framework by Creswell and Creswell (2017).

#### 8.3.6. Participant feedback

Figure 8.3 shows the participants' reactions to the following statements: "I perceive the risks related to Critical Raw Materials (CRM) as more urgent than before the workshop", "Thinking in scenarios contributed to my awareness of future risks", "I would apply scenario planning to reflect on other strategic risks" and "The workshop helped with implementing strategy within my company".



**Figure 8.3:** Respondents' opinions on the workshop

Right after the workshop, participants were asked how they experienced the workshop, and specifically how the scenario planning part was experienced compared with the first part in which information was supplied. As shown in Figure 8.3 the workshop was highly effective in raising risk awareness, with three of the four participants 'totally agreeing' that thinking in scenarios contributed to this outcome.

### 8.3.7. In-workshop reflections on scenario and awareness

Participants reflected on the scenario-based part of the workshop as particularly effective in increasing their awareness and sense of urgency:

*"I thought it was really good. The way you got us thinking about several aspects and guided us through one or two of those tipping points. It made you not just watch passively, but actively participate, which really helped it stick better."* (AW3 – understanding tipping points, CT1 – Workshop Format)

This response highlights how the scenario structure and facilitation style encouraged active involvement, which helped participants internalize the message. It reflects increased awareness through engagement and design appreciation.

*"You actually need to know something about the topic before you're willing to spend time on it. Now, through your story, we got a foot in the door and then it really came alive."* (AW4-relevance to company, AW9 – Blackspot awareness, CT1 – Perceived usefulness)

This quote suggests that participants previously had little knowledge about the topic and now they do, relating to the relevance to the company (AW4). Also participants previously did not realise the impacts, showing awareness of a previous blackspot. Stating the workshop made the topic come alive shows a perceived usefulness of the tool.

*"I really found it an eye opener. [...] But now that we've heard the underlying context, you see the bigger picture."* (AW1 – Information Clarity, SU2 – Strategic Importance)

This quote illustrates how the scenario provided a contextual overview that shifted the participant's perception from isolated signals to a more systemic understanding of CRM-related risks.

The workshop received positive responses from participants. The written reactions are translated and

labeled with the concept codes. Asked if participants would recommend the workshop to sector peers, the reactions were:

*"Absolutely do it, and share knowledge to make progress together and develop alternatives."*  
(CT1, ST5-although not comparative but rather cooperative)

This participant emphasized the importance of knowledge sharing and collaboration, which reflects both a positive reception of the tool (CT1) and a proactive stance towards strategic development (ST4).

*"Yes, it raises awareness, and the design of the workshop makes it very accessible."* (AW, CT2)

Here, the participant clearly indicates that the workshop increased awareness (AW), and also appreciates its accessible design, indicating perceived ease of use of the communication tool (CT2).

*"It will definitely help us and other companies as well. However, this problem is too big for a single company, we will need to address this as a sector, together with the scientific community (e.g. Techniek Nederland)."*  
(SU, ST, CT)

This response points to a strong sense of urgency (SU2) and highlights the need for sector-wide coordination and institutional support, indicating a strategic outlook (ST2). Also, it indicates that the workshop has helped the company, showing a perceived usefulness (CT1).

## 8.4. Conclusion

The results of this study reveal that the scenario planning workshop effectively raised awareness and a sense of urgency about CRM dependence, and its associated supply risks, among participating professionals. Thematic analysis of pre- and post-intervention questionnaires and interviews indicates a greater understanding of supply risks, a greater recognition of CRM relevance for corporate strategy, and a generally positive reception of the communication tool. In terms of feedback and evaluation cycles as part of the AR aspect of the workshop, the participants appreciated the ability of the workshop to stimulate reflection and discussions, although some uncertainty remained regarding direct follow-up actions. These findings suggest that scenario planning can play a role in catalysing internal engagement and laying the groundwork for a strategy related to CRM challenges. The next chapter discusses these findings in light of the existing literature and assesses the implications for organisational change and policy support mechanisms.



# 9

## Discussion

The discussion consists of two parts: the interpretation of the findings and the limitations of the research. In the interpretation, quantitative and qualitative data are synthesised to analyse how they align or diverge. In addition, it is discussed how the findings of this research relate to and build on the existing literature. Through this analysis, the main research question is addressed: whether a communication tool can be used to increase awareness and create a sense of urgency around CRM supply risks in companies. The second part outlines the theoretical and practical limitations of this research, providing important context for the interpretation of the results.

### 9.1. Summary of findings

The AR conducted during this research demonstrated that the implementation of a scenario planning workshop is an effective way to increase awareness and create a sense of urgency toward the risk of CRM supply among participants. After the workshop, participants clearly expressed the desire to be more aware of the risks they faced, as CRM changed from a distant issue to something that could actually hurt their company if not addressed. This shows both a understanding of direct implications of CRM supply risks on the company and a sense of urgency to reduce this risk through mitigating strategies. The qualitative results clearly support this notion of increased awareness and a sense of urgency towards the issue, for example, expressed through feedback and additional outreach. However, quantitative results such as Figures 8.2 and 8.3 provide a more mixed result. CRM supply risks do not appear to gain prioritisation compared to other strategic risks. In addition, half of the participants view short-term problems for the company as unlikely. This apparent contradiction shows the challenges of quantitatively measuring subjective constructs like 'urgency' and may reflect the 'question ambiguity' discussed in the limitations, Chapter 9.3. At the same time, it shows the value of the mixed-method approach for data collection and analysis, as this allowed for triangulation of the various observations.

In addition to the measured results, an important facet of AR is interactive cooperation with the participants. To quote one of the founding members of the AR school: "In participatory research, you can help people see their own problems. You do not tell them, 'This is your problem', but you work with them so that they become active" (Bradbury et al., 2019). Although the facilitator had an active role in the workshop, brainstorming and listing of solutions was done solely by participants. Therefore, the practical outcomes of the workshop can also be seen as the results of this AR. The final format of the workshop, including the worksheets implemented after adjustments in the pilot evaluation cycle, was shown to be effective in guiding the participants to take the first steps toward the creation of mitigation strategies. By following set steps, including risk assessment, identification of opportunities or mitigation possibilities, grouping of mitigation categories, and filling in of mitigation strategy worksheets, this resulted in the outline of practical steps in order to implement the strategies. Involvement of participants in strategising, combined with successive action taken after the workshop, indicates support for change within their organisation.

The last key goal of AR is to uncover unrecognised assumptions, which can either limit or enhance the transformational process. The collection of data and observation during this thesis has exposed some assumptions and opportunities, which will be introduced in the key findings section.

## 9.2. Interpretation of key findings

This section will argue why the workshop had the desired effects as an implementation tool on participants and address unrecognised assumptions in the field of CRM risk awareness. These goals align with the key reasons for implementing AR as argued by Bradbury et al. (2019).

### 9.2.1. Power of narrative and interaction

This study suggests that due to the narrative and participatory nature of the intervention, the SP workshop can serve as a starting point for organisational discussion of CRM risk. The participants highlighted these aspects as the main catalysts for their increased awareness of risk. During the workshop, participants had several 'aha' moments, emphasizing they had seen bits of information on CRM-related topics in the media and during their work, but had never been able to string this information together in a coherent story. Participants ascribed their increased sense of urgency for CRM supply risks to the active interaction with the scenarios through which the effects it would have on their company 'clicked'.

During the workshop, interaction and cooperation played key roles in influencing perceptions of risks, as well as the outcomes in the form of practical strategies ideas. The participants influenced each other, demonstrating the importance of interaction during the workshop. Communication and cooperation on the problems at hand appeared to improve understanding of the risks, as well as elevate the level of mitigation actions and strategies, making them more appropriate to mitigate the risk of CRM supply. The initial ideas proposed focused on stockpiling and contracting, after which the participants themselves concluded that these solutions would only bridge temporary disruptions and not safeguard the company in futures where materials were even more critical. This was followed by solutions focused on gaining internal knowledge and prioritising materials, aligning with the findings of Chapter 5. During the discussion, these ideas evolved into sector-wide initiatives, ranging from sharing knowledge to cooperating with other companies in their sector.

### 9.2.2. Sense of urgency as a driver for change

The theoretical framework theorised that change, in the form of mitigation strategies, is only supported if a sense of urgency is experienced by company decision-makers. During this research, this causal link was confirmed in various ways. Participants indicated a belief that CRM risk would prove to be a problem to their company in the long term (>10 years) in the pre-workshop questionnaire of both the workshop and the pilot. The initial lack of policy and action indicates that having knowledge about the long-term risks did not drive the integration of mitigation strategies. While participants were generally aware of long-term risks of CRM dependence, mitigation strategies were found to be non-existent within the company.

In the post-workshop discussion, participants mentioned that the new insights they gained on the short-term disruption risks in the workshop had raised their sense of urgency towards CRM risk, and stated that this was the main drivers towards a willingness to initiate change within their company. This aligns with theories of psychological distance by Spence et al. (2012), who stated that risks that feel far away people are not likely to feel a sense of urgency, and Kotter (1996a), who stated that this sense of urgency is essential if change is to be implemented in a company.

### 9.2.3. Black-spot awareness and material understanding

A key part in understanding companies' perspective towards CRM risk awareness is captured by the concept of 'Black-spot awareness.' Quantitatively, this has been the concept most often mentioned in the interviews. The recurring observation was that the company had very little knowledge of its supply chains beyond its tier 1 suppliers. There were several constraints mentioned which caused black-spots in the supply chain, as well as a normalised perspective of having little to no knowledge of the contents of products for companies that are part of downstream technology supply chains.

Therefore, the proactive attitude towards understanding material content after the workshop is a major shift from the passive stance toward material understanding before participation.

One of the key mitigation strategies pursued was 'gaining insight in products (containing CRM) as a company'. This shows that blackspot awareness can be closely linked to the first sub-concept of organisational strategy, ST1 - the material assessment. Material assessment is often listed as an important first step in CRM mitigation strategies in the previous literature by Griffin et al. (2019) and Kolotzek et al. (2018). Creating a new perspective of the current unawareness of material contents (AW2) with the associated risks of CRM supply disruptions on the company (AW4) can be strong combined

drivers for strategic action within a company.

The importance of participants having an understanding of an element-product link, in the sense that there is CRM in their company's value chain, even though the company does not physically handle raw materials, aligns with the findings of previous research. Whalen and Peck (2014) suggested that a low element-product link might be an obstacle to the formation of a CRM relevant strategy. In fact, participants mentioned that they had previously not connected news items on REE disruptions to their own reliance on magnets.

Although no material comparison was mentioned by any of the participants before the workshop, this was one of the main themes during the discussion and presentation of mitigation proposals. The participants were keen to first find the most critical materials and parts in their organisation, before exploring how specific strategies could reduce these risk factors. This showcases how the workshop improved the understanding of the concept of criticality. In addition, it affirms the theoretical link from *risk awareness* to *willingness to act*.

The relevance of additional research on critical materials in products was highlighted by the perceived barriers to doing this from a company's perspective. It was expressed that understanding the contents of the material as a company would be too difficult. As cooperation with most suppliers was difficult, not least due to the sheer number of them, which could be in the thousands, undertaking this endeavour as a company was considered a 'monstrous task' due to the time necessary, and the fact that the company itself would bear all the costs. The participants expressed great interest in contacting knowledge institutes and universities to outsource critical materials assessment in their supply chains. Previous studies conducting criticality assessments for specific parts and products, e.g. superconductors (de Pooter et al., 2022), heat pumps (Bos, 2025), and 13 other technical products (Carrara et al., 2023), were perceived by the participants with great interest.

#### 9.2.4. From material-level to part-level thinking

This research findings add to the notions in previous research that thinking in parts can actually improve understanding of criticality. The work of Lapko et al. (2016) concluded that manufacturers are primarily concerned with physical availability and the performance of their immediate suppliers. The finding from previous CRM awareness studies that (Whalen & Peck, 2014, Companies think on a component level rather than a material level) was confirmed during the interviews and workshop observations in this investigation. This can be used as a key piece of information in bridging the knowledge-awareness-urgency link. A new observation is that participants had experienced parts criticality in the form of supply disruptions in the past, while the concept of material criticality remained more abstract. Therefore, my research suggests that for downstream companies, a more effective entry point for a discussion on criticality is one they already understand: the risk of not getting the right part at the right time. Viewing criticality from a product level makes the concept of criticality more relatable and close, two key concepts in the building of awareness and a sense of urgency.

#### 9.2.5. Focus on supply risks and disruptions

All participants, as well as other business professionals contacted, stressed the importance of approaching CRM from a supply risk perspective to gain traction within their business. As detailed in SQ1, Chapter 5, CRMs have a multitude of associated risks and impacts. However, qualitative observations and quantitative results show that there are substantial differences in how problematic these risks are perceived by the company. Linking this to the conceptual framework; Some risks have less *perceived relevance*, not inducing the *sense of urgency* necessary for the initiation of mitigation strategies.

Although participants often stated that they were aware of the negative environmental and social effects associated with CRM extraction, participants stated that awareness of these risks would not likely be a driving force to initiate concrete action within the company. This aligns with the qualitative context that I gained through personal correspondence with other company stakeholders, including sustainability managers, who underlined the prioritisation of supply risks received in their company compared to topics of ESG. Although some participants and external stakeholders expressed that they were driven by sustainable impact themselves ('doing good'), they viewed a sustainable approach of CRM issues within the company as unfruitful, as in the end this would not stand against commercial interests. Supply risk, on the contrary, hits where it hurts most and is therefore likely to be taken seriously within the company context.

### 9.2.6. Circularity and CRM

A primary focus on supply risk aspects does not mean that ESG aspects of CRM should be neglected when communicating CRM risk to companies; however, they could be viewed in terms of mitigation strategies rather than risks. This finding is based on the observation that the concept of circularity was a recurring theme during the interviews and workshop and a settled concept within the business environment. The company already experiences external pressure to initiate circular initiatives due to circularity targets from customers. Future government legislation, such as the National Materials Strategy (Ministerie van Economische Zaken en Klimaat, 2022), may be drivers of circular initiatives for companies. Academic research, such as Gaustad et al. (2018) and Peck (2016), and policies, such as the CRMA (Commission, 2023b), highlight the need to close material loops as solutions to mitigate CRM dependency, and connecting existing circular drivers to the field of CRM can be an effective driver to increase CRM knowledge and initiate circular initiatives focused on CRM. Previous studies, such as Gaustad et al. (2018), have shown the potential to mitigate risk through the implementation of circular initiatives. Communicating circular CRM-strategies as a win-win solution, mitigating risk, and improving environmental performance, may prove to be a powerful driver towards the implementation of mitigation action.

### 9.2.7. Building sectoral cooperation

A key finding from this research is that mitigating CRM risks is not something a company can or should do alone. Therefore, sectoral cooperation can be a key catalyst for the initiation of mitigation strategies.

Participants in the workshops expressed interest in reaching out to other companies to exchange information and combine forces to mitigate the risk of CRM, as they felt that all companies in their sector would face the same risk as them. The difficulties mentioned for conducting their own assessment or mitigation strategies included financial constraints, where they would not be able to pass down any of the costs incurred in these assessments. Therefore, participants were eager to contact industry peers, either directly or through the branch organisation, as they felt the risk was equally important to them.

This is a new finding, as previous research often looked at companies as individualistic, highlighting their secrecy and privacy surrounding material content and suppliers Peck (2016). In addition, research on firm-level criticality assessments, such as Griffin et al. (2019), did not mention the cooperation with other companies. Although some research is directed at specific sectors, mainly renewable energy, defence, and e-mobility (Carrara et al., 2023; Patrahau et al., 2023), for most sectors there is no guidance or policy available. Through cooperation, companies could develop guidelines that could help mitigate the risks of CRM across the entire industry. Approached from a top-down perspective, governmental assistance in the creation of such guidelines can assist companies in taking the first steps towards the creation of an effective CRM mitigation action, which prevents each individual company from inventing the wheel again. These actions have been mentioned in the recommendations for policymakers, Chapter 10.

Because it was not mentioned in previous research, the concept of cooperation was not captured by the conceptualisation. The introduction of a sixth strategy subconcept, ST6 - Cooperativeness, might capture an important factor when capturing the organisational stance towards CRM-based strategy.

Although this research highlights the benefits of cooperating, it has not been studied whether increased cooperation could actually mitigate risk or the impacts of disruptions in practice. Apart from that, the willingness to cooperate might also be a difference between companies physically producing parts and companies which are further down the supply chain, which assemble or purchase readily made parts and products. These questions have been added as recommendations for future research in Chapter 10.

## 9.3. Limitations of the research

This study offers valuable information on the awareness and sense of urgency towards CRM supply risks in a business context, and the potential of a scenario planning workshop to enhance this awareness, but several limitations inherent in its design, scope, and execution must be acknowledged. This section first discusses theoretical limitations, defining what this thesis can and cannot achieve by its design and theoretical framework. Then practical limitations are covered; execution and feasibility challenges in methodology and data collection. Subsequently, on the basis of these identified constraints and the insights gained, concrete directions for future research will be proposed.

### 9.3.1. Theoretical limitations

#### The theoretical basis of the change model

One of the main theories on which this thesis is based is Kotter (1996a) 'leading change.' There has been some critique on the book, as it is completely based on James Kotter's own experiences, featuring no citations of any other sources. However, the book has seemingly been accepted by the scientific community, being cited over 23.000 times in Google Scholar. Appelbaum et al. (2012) cites (Todnem, 2005) who stated: (Todnem, 2005, Theories and approaches to change management currently available to academics and practitioners are often contradictory, mostly lacking empirical evidence and supported by unchallenged hypotheses concerning the nature of contemporary organisational change management). Although this was true in 2005, Appelbaum et al. (2012) revised the theory in 2012, trying to value the 8-step model. They find various sources agreeing with the main message that urgency is necessary in order to drive change, and therefore conclude that a sense of urgency is indeed the appropriate first step in the change process. Due to the support of the scientific revision by Appelbaum et al. (2012), along with the widespread adaptation by the scientific community, this led to the selection of the theory for the theoretical framework of this thesis.

#### Internal validity

Internal validity concerns issues that can falsely indicate a causal relationship between action and effect, even though there is none. One of the main threats to internal validity in this research is the use of the author of this article as the facilitator of the SP workshop. Having personal contact and feeling the willingness to assist in research, this might make participants feel obliged to rate their perception of the workshop more highly (Hart et al., 2020). Another form is the social desirability bias, where people respond in a way which they believe is expected rather than what is true. These biases have been mitigated by explicitly stating at the start of the interviews that any information is useful for the research, also if it is a negative critique of the method or if they had expectations which were not met.

#### Measurement validity and biases

The quantitative assessment of awareness and the sense of urgency is based on the self-reporting of participants in questionnaires, which can be subjective. A self-assessment bias can influence outcomes if people overestimate their understanding of what they have learnt, also known as the Dunning-Kruger effect. Another way in which results can be influenced is through an unintentional social desirability bias. Participants may have indicated an increased sense of urgency due to a perceived expectation to respond positively in a group setting. This may not have affected them when filling in the PoWQ due to the more anonymous nature of an online questionnaire, allowing more critical responses. However, since no individual qualitative post-workshop interviews were conducted, it was not possible to verify these biases.

Through the sub-concepts, it has been attempted to make an estimation of a sense of urgency, since the lack of a single definition of urgency makes it difficult to objectively compare what people think of as urgent. Another way in which it has been tried to make the sense of urgency quantitatively comparable is through the relation of the sense of urgency felt towards other issues. Between the pre- and post-interview the sense of urgency towards other issues is assumed to be stable, which would show the relative change of sense of urgency towards CRM risks.

However, contrasting results between the rich qualitative data and the more modest quantitative findings suggest that these mitigation efforts were only partially successful. This points to two potential issues, construct validity of the questionnaire and question ambiguity. These limitations are supported in the following sections. These issues are inherent in psychological research, so it is recommended to include psychology experts to resolve these issues in Chapter 10

#### Construct validity of the questionnaire:

The questions may have failed to capture the intended psychological constructs of awareness and sense of urgency. Direct questions about awareness were not included to avoid social desirability bias, but this may have reduced the direct application of the questions to constructs. For example, estimating the chance that CRM supply risks will be a problem does not measure either of the concepts explicitly, but rather asks for the estimated impact on the company. It has not been studied whether this is based on other constructs such as perceived risk.

#### Question ambiguity:

Some quantitative questions asked in the questionnaire could have been ambiguously interpreted. In the question where participants have to rate and rank the likelihood that CRM risks are a problem for their company, participants may have interpreted the question as the impact of the risk with or without mitigation strategies. For the latter, including the company's response in estimating the risk leads to a reduced impact. Including interviews after the workshop would allow for verification of these questions and is therefore recommended for future research.

#### Limited use of operationalised concepts

The conceptualisation served as a valuable analytical lens for qualitatively interpreting the responses of the participants before and after the workshop. The structured framework has been used for structuring opinions and statements related to awareness (AW), sense of urgency (SU), strategic orientation (ST), and communication tool acceptance (CT). The discussion of the findings highlighted several changes made in the evaluation cycles. However, the limited number of workshop cycles and the exploratory nature of the study limited the potential for quantitative analysis or code frequency comparison. Therefore, the concepts were applied qualitatively to support thematic interpretation rather than statistical validation. This limitation emphasises the need for follow-up studies with a larger group of participants to assess the robustness and generalisability of the observed thematic patterns, as recommended in Chapter 10.

### 9.3.2. Practical limitations

#### Sample size

The empirical basis of this study consisted of two phases: a pilot workshop with seven participants (six of whom completed both the pre- and post-workshop questionnaires) and a main case study workshop with four participants from a single organisation. The four case study participants participated in pre-workshop interviews, pre- and post-questionnaires, and a post-workshop evaluation session.

The sample size for the participatory workshop was relatively small due to the intensive nature of the intervention and practical restrictions in participant recruitment. Although there is no set minimum sample size in qualitative or mixed-method research, scholarly consensus generally emphasises the concept of thematic saturation, which means that the addition of participants does not lead to additional study findings (Hennink & Kaiser, 2022). Based on the degree of alignment across the participant responses in the pre-workshop interviews and expressed levels of awareness and sense of urgency after the workshop, it can be argued that thematic saturation was achieved within the qualitative component of the study.

One way of contextualising the workshop is to see a workshop session as a single focus group intervention. Academic precedent suggests that two focus groups can be used to identify most themes within a data set (Guest et al., 2017). Having conducted the workshop as both a pilot with professionals and a workshop with industry stakeholders, it can be argued that qualitative findings are academically acceptable, as other studies investigating the effectiveness of workshops have relied on two focus groups to generalise their findings (Billington et al., 2009).

However, the quantitative analysis of the workshop's PWQ and PoWQ results could not be generalised due to the low statistical power of the sample size ( $n=4$ ). The results could be compared with the results of the pilot, which had a sample size ( $n = 7$ ). These findings could not be combined to form a single larger sample pool, as the questions were altered inbetween and did therefore not align.

#### Longitudinal effects

The time elapsed between the workshop and the post-workshop interview is relatively short, meaning that the study captures an immediate change of awareness and a sense of urgency rather than long-term behavioural changes. Within the scope of this research, it was not possible to validate with the company involved whether the actions listed on the worksheet were put into practical action within the timeline filled in the worksheets. It would be very interesting to measure the risk awareness and willingness to implement mitigating strategies for CRM after a longer time-span to see whether initial awareness has increased due to more understanding of the topic in work activities and the media, or decreased due to other preoccupations.

Similarly, it would be very relevant for the evaluation of the effectiveness of the SP-workshop on actual change in the company to learn whether the implementation leads to practical change in the companies where it is implemented.

## 9.4. Implications of the research

### 9.4.1. Methodological contribution

This research makes two interconnected methodological contributions to the study of company risk perception and is a practical tool for practitioners.

### 9.4.2. Condensed scenario planning tool

This study demonstrates a novel application of the scenario planning methodology. In previous studies, scenario planning was used mainly to uncover future perspectives for companies. Although increased awareness is often mentioned as one of the key outcomes of SP workshops, no previous SP has been conducted with the main objective of increasing awareness and the sense of urgency for a certain risk. In that perspective, this research builds on previous research by showing that SP can be used as a tool for highlighting a specific risk in a company setting, raising awareness and a felt sense of urgency for the topic discussed.

This research has condensed the scenario planning format to a 3-hour workshop in which participants could participate without prior knowledge. The results of the workshop show that the goals set could be achieved in a 3-hour session. A time constraint barrier has been mentioned as one of the main limitations of the SP methodology in previous SP research (Thomson et al., 2020). This research shows that the highly condensed scenario planning format can be effective, thereby broadening the applicability of the SP tool for resource-constrained organisations or time-constrained managers. This has been an essential modification for the tool to be successfully implemented as an awareness creation tool, partly overcoming the awareness paradox elaborated in the limitations 9.3.

### 9.4.3. CRM awareness assessment model

A novel conceptualisation framework for CRM risk awareness assessment is introduced in this study. A set of concepts are interconnected through a novel theoretical framework: Awareness (AW), Sense of Urgency (SU), Strategic Orientation (ST), and Communication Tool Acceptance (CT). Prior to this research, no such framework existed in literature, limiting the objective measurement of these concepts in research focussing on the causality between knowledge, awareness, a sense of urgency, and practical implementation of strategy. These topics are understudied in general, within the field of CRM there exists a complete gap in prior conceptual frameworks concerning these topics. A conceptualisation table is designed to better capture different dimensions of how people and organisations perceive and respond to CRM-related risks. These concepts provided a structured lens for analysing qualitative data and may serve as a useful analytical framework for future studies on CRM risk awareness. The framework had to be built from separate sources from the literature as there was no combined conceptualisation for risk awareness, sense of urgency, and organisational CRM strategy.

# 10

## Recommendations

### 10.1. Recommendation for researchers

#### 10.1.1. Expand the sample pool

Due to the scope of this research, the effect of the workshop has only been evaluated in two company settings. Therefore, the main recommendation for further research is to facilitate the workshop in more companies so cross-company analysis can be performed. Cross-sectoral findings can show whether the findings of this investigation are specific to the company or people involved, as there is currently no reference material to compare the results. This is a particular relevance issue in the wider field of CRM risk mitigation, as research by Griffin et al. (2019) has already questioned how organisational design, communication, and culture within a specific firm impact implementation and attitude towards critical material supply chain risks.

#### 10.1.2. Conduct a longitudinal study

Although this study showed an increase in expressed urgency, a crucial next step is to conduct a longitudinal analysis to track how this urgency translates into corporate action over a 12- to 24-month period. This would answer the question whether there is a causal connection between the expressed support for mitigation strategies and the practical implementation of mitigating strategies, a challenge previously raised by Griffin et al. (2019). As the goal of this tool is to have a practical impact on society, as Action Research prescribes, it is highly relevant to study the practical effects of the implementation of the tool in companies.

#### 10.1.3. Introduce a framework for circular impact of mitigation strategies

Comparison of different mitigation strategies with CRM supply risks remains an understudied field. Although established models such as the 9R model as described by Potting et al. (2017) can be applied to analyse these mitigation actions, there is no model specifically altered to compare mitigation actions in the field of CRM. Building on the work of Peck (2016), the introduction of a framework which evaluates circular economy strategies would help companies differentiate between risk buffering strategies such as stockpiling, and risk reduction strategies such as design for circularity. Having such a framework could assist in the reduction of CRM demand and support companies towards strategic advantage and positive impact.

#### 10.1.4. Research sectoral cooperation as mitigating factor

One of the main findings of this research is the lack of information on the willingness of companies to cooperate with other companies and the effectiveness of cooperation in the implementation of mitigation strategies. Some previous research, such as the work of Whalen and Peck (2014), indicates that companies are reluctant to discuss critical material challenges. However, studies focused specifically on inter-company cooperation in the context of CRM were not found. More research on how willing companies are to cooperate within their sector in the mitigation of CRM-related risks is essential to better understand the potential for cooperation.



### 10.1.5. Include psychologists in the field of CRM

As highlighted in the literature study, Chapter 2.3.3, psychology is an important aspect of why inaction persists, as even if it is clear that there is a problem and mitigation actions exist, this does not automatically drive change. Although climate change psychology has received quite a bit of attention in previous years, for example, in studies on psychological distance (Van Lange & Huckelba, 2021), it should be noted that no single study has been found that studies the perception of CRM risk from a psychology perspective. This research found that the field of CRM risk from a company perspective remains understudied, particularly the psychological factors of how CRM risks are perceived and why inaction persists. Psychology-focused studies could clarify and empirically substantiate these concepts, mitigating the construct and internal validity mentioned in the limitations, Chapter 9.3. Therefore, it is recommended to include researchers with a psychologic background in the field of CRM to gain a better understanding of why there is corporate inertia and how this could be overcome.

### 10.1.6. Improve semantic uniformity

In my experience, the use of the term "critical raw materials" leads to a number of problems. The term is used most commonly in the European Union, while other regions tend more toward other terms such as 'critical minerals' or 'critical materials.' This limited the amount of initial literature found. Apart from this obstacle, the term might induce unintentional resistance from companies. As mentioned in the study, the element-product link is one of the obstacles to a sense of urgency in companies. Reference to raw materials might confirm this bias, as companies that do not handle raw materials may therefore feel the topic is of little relevance to them. The effect of semantics could not be studied within the scope of this thesis, but for the author, it seems a relevant topic to research. As the topic of CRM will only increase in importance in the coming years, choosing the right language might be of significance in how the topic is addressed. This is in line with the call for disambiguation of Adamo et al. (2024), who studied the effects of semantics in the management of risk of climate change issues.

## 10.2. Recommendations for policymakers

### 10.2.1. Support implementation of awareness tool in Dutch business

This research has shown the potential of the implementation of an awareness building tool in companies to improve awareness of CRM risk. Therefore, it is recommended that government bodies, in partnership with industry associations, pilot and subsidise the rollout of condensed scenario planning workshops as described in this thesis. Previous research by Bastein and Rietveld (2015) showed the dependence on the import of finished and semi-finished goods in the Netherlands, a downstream economy. This makes awareness at the company level essential to reduce the overall material demand of our society. A bottom-up approach empowers companies most exposed to hidden upstream supply disruptions and complements the national top-down strategy. The workshop is time and resource efficient and can therefore be considered low-hanging fruit in the strategy towards a more material-independent society.

### 10.2.2. Support sectoral collaboration

My research has found that the companies involved expressed the need for more guidance in assessing and mitigating CRM risks. For policymakers, it is recommended to actively contact industry organisations to highlight the issue and provide guidance in industry-specific prioritisations regarding CRM strategies. Most of the companies contacted during this thesis showed interest in the topic, but for many, the topic was seen as too intangible to prioritise over day-to-day concerns. Policies such as the National Material Strategy can form a solid groundwork for more sector-specific cooperation. However, three years after its introduction, information on the implications of the policy remain scarce and effects of the policy are therefore unclear.

### 10.2.3. Subsidise circular initiatives

Circular initiatives to improve closed-loop CRM initiatives meet several obstacles, most prominently, the unfavourable financial business case. Due to high labour costs and low material prices, at this time, it is not viable for companies to initiate their own circular initiatives. This unfavourable economic situation has been previously mentioned in research, e.g., in Gaustad et al. (2018). The call for governmental investments is in line with the National Innovation Agenda Critical Raw Materials (Nationale Innovatieagenda Kritieke Grondstoffen), a cooperation of the Chemical topsector and MaterialsNL. In this agenda, they recommend the government invest at least €300 million to support circular initiatives, as industry and business are likely not able to do so themselves. This would be able to bridge the financial gap towards

circular initiatives, and this call is therefore strongly supported by this research.

#### 10.2.4. Support material education

In light of the growing importance of (critical) materials in the Dutch economy, it seems contrasting that a department focussing on these topics is being closed, instead of supported. The closing of the Earth Sciences Department at the Vrije Universiteit in Amsterdam has faced fierce resistance from both the educational field and the business reliant on new expert employees (Heimovaara & Geiger, 2025). The lack of specialists in the field of CRM has previously been mentioned by researchers in the field, e.g., in the dissertation of Peck (2016). The companies contacted during this thesis indicated that they depended on universities and knowledge institutes for information on critical materials. The call for experts in materials, recycling and criticality is likely to be even stronger in the future. As there is already a shortage of experts in the Netherlands, these problems will only become worse if more businesses experience the impacts of critical material supply disruptions. Therefore, it is strongly recommended to reverse the cuts in education and instead invest in one or several new specialised critical material departments, a yet nonexistent specialisation in the Dutch education ecosystem.

# 11

## IE perspective

### 11.1. Systems thinking

This research has shown the importance of an interdisciplinary approach to CRM issues in a business context. Focussing on the sustainability aspects of CRM remains important, but has not resulted in a sense of urgency to initiate large-scale industry action to reduce CRM demand. Focussing on supply risk departments can be a more promising way to approach the topic as to reach the levels of management in companies required in companies to make actual changes to policy.

### 11.2. Addressing sustainability and circularity

As outlined in the introduction and SQ1, CRM have a considerable environmental impact. Due to expected growth in demand, this impact is expected only to increase. CRM reduction strategies can reduce demand, and that way be environmentally beneficial. CRM can go hand in hand with circularity initiatives, hooking onto existing initiatives and initiating circular initiatives for products that previously had linear chains. The problems surrounding CRM show the importance of thinking in global supply chains rather than individual operations. This research has shown how different fields: risk, supply chain management, management communication, material science, and sustainability can go hand in hand to work toward a more circular society.

#### 11.2.1. Transdisciplinary approach

In the development of the SP tool, this research went beyond interdisciplinary approaches and adopted transdisciplinary approaches during its AR cycles, as described by OECD (2020). Participatory engagement was involved to better understand perceptions and expectations of the problems and possible tools to create societal change. Dialogue with stakeholders and co-creation with companies outside the scientific realm, as described in 4.2.1, has resulted in a more applicable and practical solution.

#### 11.2.2. AR in IE

One of the core objectives of AR is to use research to have a practical sustainable impact (Bradbury-Huang & Reason, 2007). The results of the workshop show that this research has successfully met that objective. The participating company is actively taking steps to assess its CRM dependence. In addition to mapping their own dependence on CRM, the company is actively reaching out to sectoral peers, aiming to form coalitions to achieve systematic change. As such, the AR approach shows to be well aligned with the principles of Industrial Ecology, which emphasise systems thinking, stakeholder engagement, and practical pathways towards sustainability.

# 12

## Conclusion

This research aimed to answer the research question: *How can awareness and the sense of urgency of Critical Raw Material (CRM) supply risks in companies be increased through a communication tool?*

To answer this question, three supporting sub-questions were constructed, for which the outcomes will be summarised in this chapter.

The literature review shows that there is no actualised overview of CRM supply risks relevant to companies in the Netherlands. This led to the first sub-research question, *'What are the main supply risks associated with companies' dependence on CRMs?'* Desk studies showed that, from the myriad of uncertainties and risks in the field of CRM, the key uncertainty relevant to companies is the risk of supply chain disruptions due to export restrictions. Due to the increasingly limited spread in production facilities, export restrictions from single countries can disrupt many material and product supply chains. China in particular has created a near-monopoly on dozens of materials, either in extraction, refinement, manufacturing, or ownership of companies somewhere in the supply chain. Limited alternatives, combined with rising global tensions and increasing amounts of export restrictions, increase uncertainty for many companies dependent on imports of CRMs or products containing those materials.

The next step of this research consisted of the comparison of several management communication tools to answer the second sub-question *'What communication tools can increase risk awareness in companies?'* Scenario planning was selected as the most appropriate tool in this context, most importantly due to its replicability, feasibility, and previous validation in different contexts.

After selecting this tool, an action research (AR) approach was adopted. This included the participation of experts and business representatives in the construction of the scenario planning workshop and the active participation of business representatives in the evaluation of the tool in practice. As is common in AR, several feedback loops were included during tool evaluations, both in the pilot and in practice sessions. The final format of the tool is described in SQ2 and SQ3 of this research.

The scenario planning workshop was found to be an effective tool to increase awareness and create a sense of urgency for CRM supply risks within companies. The participants in the workshop expressed an increased understanding of the topic of CRM. In addition to that, they expressed a sense of urgency to mitigate the CRM supply risks in their company. The combination of receiving information on the topic of CRM and actively interacting with a set of different future scenarios through the formation of a strategy was expressed as a key to their increased awareness of CRM risks.

Recommendations for further research include the expansion of the sample pool to increase the external validity of this research, which is one of its main limitations. In addition, conducting longitudinal research with workshop participants to investigate whether awareness gained during the workshop is lasting and how this is translated into practical action within the company.

This study contributes to the emerging body around CRM communication strategies by creating a CRM-focused scenario planning workshop. Although scenario planning is an established management tool, it has never been reported to be used in the fields of material supply risks or CRM.

Although some strategies were found to have environmental benefits through reduction of material

demand or increase in circular initiatives, other strategies, such as stockpiling or contractual supply commitments, do not. It has to be further studied how companies can be steered towards environmentally beneficial strategies in order to reach a more sustainable material society.

Ultimately, this research demonstrates that tackling the complexity of Critical Raw Materials begins not with a new policy mandate alone, but with a new conversation. The condensed scenario planning workshop is a practical and powerful tool to start that crucial conversation, transforming abstract risks into actionable strategies, providing a 'critical eye-opener' as a catalyst for a more resilient and sustainable future.

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# Appendices

## A. Conceptual framework for analysis

### Legend of Codes:

- **AW** (Blue) – Awareness
- **SU** (Orange) – Sense of Urgency
- **ST** (Green) – Organizational Strategy
- **CT** (Yellow) – Communication Tool Acceptance

**Table 1:** Conceptualization

Concept	Sub-concepts	Explanation and reference
<b>Awareness</b>	AW1 – Material familiarity	Participant correctly defines CRMs, mentions specific CRMs relevant to their industry/company, or discusses the concept of material criticality. (Peck, 2016)
	AW2 – Element-product link	Participant explicitly links specific CRMs to products purchased by their company. (Whalen & Peck, 2014)
	AW3 – Risk understanding	The person understands which supply risks are associated with CRM. (Peck, 2016)
	AW4 – Relevance of CRM risk to organization	Participant articulates why CRM supply risks are (or are not) important for their organization. (Peck, 2016)
	AW5 - Solution Awareness	Awareness of existing or potential ways to address CRM risks, e.g. product design or substitution (Peck, 2016).
	AW6 – Understanding social sustainability	Links CRM to social sustainability. (Graedel et al., 2012; Kolotzek et al., 2018)
	AW7 – Understanding environmental sustainability	Links CRM to environmental sustainability. (Graedel et al., 2012; Kolotzek et al., 2018)
	AW8 – Understanding circularity aspects	Awareness of circularity as a key issue. (Whalen & Peck, 2014)
	AW9 – Blackspot awareness	Awareness that there may be “unknown unknowns” in supply chain. (Cairns & Wright, 2017)
	AW10 – Observation of a changing environment	Mention of changing conditions in CRM availability or prices. Either as expectations of future, or as an intrinsic aspect of CRM (Cairns & Wright, 2017)
<b>Sense of urgency</b>	SU1 – Prioritizing risks	Participant ranks CRM risk relative to other business risks. (Kotter, 1996a) (Guan et al., 2025)
	SU2 – Perceived sense of closeness	Participant feels CRM supply risk demand immediate attention or swift action. (Guan et al., 2025)
	SU3 – Pressure to act	Expressed external pressure or felt obligation to respond to CRM risks. (Guan et al., 2025; Kotter, 2008)
	SU4 – Seeing opportunities	Urgency driven by (positive) opportunity. (Isaksson, 2019; Kotter, 2008)

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Table 1 – continued from previous page

Concept	Sub-concepts	Explanation and reference
	SU5 – Willingness to act immediately	Mentions plans or willingness to take action in the short-term (Kotter, 1996a)
<b>Organizational strategy</b>	ST1 – Material assessment	Participant or organization has taken steps (or is planning to) to improve information on CRM in value chain. E.g. assessing internal knowledge, mapping material usage. (Kolotzek et al., 2018)
	ST2 – CRM-specific strategies	Mentions (non-)existence of CRM strategies, e.g., diversification, substitution, recycling, etc. (Kolotzek et al., 2018; Peck, 2016)
	ST3 – Prioritization of materials	Prioritization of some materials over others is mentioned. (Kolotzek et al., 2018)
	ST4 – Proactive vs. Reactive Stance	Strategic posture of the company. (Mitroff & Alpaslan, 2003)
	ST5 – Comparison with other organisations	The participant or organization compares its CRM strategy, preparedness, or awareness to other organizations (peers, competitors, or sector benchmarks) (Kolotzek et al., 2018)
<b>Communication tool acceptance</b>	CT1 – Perceived usefulness	Reflections on tool's impact on awareness/urgency. (F. D. Davis, 1989)
	CT2 – Perceived ease of use	Tool usability in creating awareness or urgency. (F. D. Davis, 1989)



## B. Analysed documents for desk research (Gray Literature)

Institution behind document	Type of documents analysed from the institution
<b>IRENA</b> (International Renewable Energy Agency)	Report on the geopolitical dimensions of critical materials essential for the energy transition. (GEOPOLITICS OF THE ENERGY TRANSITION CRITICAL MATERIALS)
<b>HCSS</b> (The Hague Centre for Strategic Studies)	Analysis of vulnerabilities and breaking points in the semiconductor and critical raw material ecosystem. (Reaching breaking point The semiconductor and critical raw material ecosystem)
<b>OECD</b> (Organisation for Economic Co-operation and Development)	Inventory and analysis of export restrictions imposed on industrial raw materials. (OECD Inventory of Export Restrictions on Industrial Raw Materials 2024)
<b>HCSS</b> (The Hague Centre for Strategic Studies)	Assessment of raw material and supply chain vulnerabilities specific to the Dutch defence sector. (Raw material and supply chain vulnerabilities in the Dutch defence sector)
<b>OECD</b> (Organisation for Economic Co-operation and Development)	Report on critical raw materials vital for the green transition, focusing on production and international trade aspects. (Raw Materials Critical for the Green Transition: Production, International Trade)
<b>IISS</b> (International Institute for Strategic Studies)	Analysis of critical raw materials in the context of European defence capabilities and security. (Critical Raw Materials and European Defence)
<b>USGS</b> (United States Geological Survey)	Comprehensive summary and data on various mineral commodities, likely including production, reserves, and use. (MINERAL COMMODITY SUMMARIES 2025)
<b>HCSS</b> (The Hague Centre for Strategic Studies)	Insights from the Dutch industry perspective on advancing European mineral security. (Advancing European Mineral Security Insights from the Dutch industry)
<b>ARUP</b>	Guide on critical raw materials, specifically from an energy transition perspective. (Critical Raw Materials Guide Insights from an energy transition perspective)
<b>European Commission</b>	Study focused on critical raw materials for the European Union. (Study on the Critical Raw Materials for the EU 2023)
<b>IEA, CEEW</b> (International Energy Agency, Council On Energy, Environment and Water)	Report addressing vulnerabilities within the supply chain of critical minerals. (Addressing Vulnerabilities in the Supply Chain of Critical Minerals)
<b>IEA</b> (International Energy Agency)	Outlook and forecast concerning global critical minerals. (Global Critical Minerals Outlook 2025)
<b>JRC</b> (Joint Research Centre - European Commission)	Supply chain analysis and material demand forecast for critical raw materials used in strategic technologies. (Supply chain analysis and material demand forecast in strategic technologies)

Institution behind document	Type of documents analysed from the institution
<b>WEF</b> (World Economic Forum)	Report on strategies and considerations for securing mineral supplies necessary for the energy transition. (Securing Minerals for the Energy Transition)

## C. Pre-workshop questionnaire with concepts

**Table 3:** Questionnaire with sub-concepts

Question)	Category	Sub-concept Code(s) (from Appendix A)	Explanation
1. Wat is je naam? (What is your name?)	N.A.	N.A.	Respondent identification.
2. Stellingen over Critical Raw Materials (CRM) en risico's. (Statements on CRMs and risks.)			
2a. Ik begrijp welke risico's verbonden zijn aan het gebruik van CRM (I understand the risks associated with using CRMs.)	Awareness	AW3	Understanding of general CRM risks.
2b. Ik weet welke CRM's relevant zijn voor de producten binnen mijn organisatie. (I know which CRMs are relevant for the products within my organization.)	Awareness	AW1, AW2	Material familiarity and element-product linkage.
2c. In mijn werk ben ik in aanraking gekomen met CRM-gerelateerde risico's. (In my work, I have encountered CRM-related risks.)	Awareness	AW3, AW4	Practical experience with CRM risks and organizational relevance.
3. Zitten er CRM in de waardeketen van je bedrijf? (Are there CRMs in your company's value chain?)	Awareness	AW1, AW2	Presence of CRMs in the value chain.
4. Hoe groot schat je de kans dat de aanvoer van CRM voor jullie bedrijf een probleem wordt.... (How likely do you estimate CRM supply will become a problem for your company....)			
4a. ...op de korte termijn (<3 jaar)? (in the short term (<3 years)?)	Sense of Urgency	SU2, AW10	Perceived closeness of risk; observation of changing environment.
4b. ...op de middellange termijn (3-10 jaar)? (in the medium term (3-10 years)?)	Sense of Urgency	SU2, AW10	Perceived closeness of risk; observation of changing environment.
4c. ...op de lange termijn (>10 jaar)? (in the long term (>10 years)?)	Awareness	AW10	observation of changing environment.
5. Ik zie de volgende risico's mbt CRM als een probleem voor ons bedrijf in de komende 3 jaar: (I see the following CRM risks as a problem for our company in the next 3 years:)	Awareness	AW4	All questions ask about the relevance to the organization, but specify the source of risk
5a. Ecologische impact (bijv. door imagoschade of strengere wetgeving) (Ecological impact)	Awareness	AW7	Relevance of environmental aspects and risks.

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Table 3 – continued from previous page

Question)	Category	Sub-concept Code(s) (from Appendix A)	Explanation
5b. Sociale omstandigheden (bijv. door imagoschade of strengere wetgeving) (Social conditions)	Awareness	AW6	Relevance of social aspects and risks.
5c. Afhankelijkheid van specifieke landen (Dependence on specific countries)	Awareness	AW3	Relevance of geopolitical dependency risk.
5d. Afhankelijkheid van specifieke leveranciers (Dependence on specific suppliers)	Awareness	AW3	Relevance of supplier dependency risk.
5e. Tekorten door toenemende vraag (Shortages due to increasing demand)	Awareness	AW3, AW10	Relevance of market-driven shortage risk.
5f. Gelimiteerde natuurlijke voorraden (Limited natural reserves)	Awareness	AW1, AW3	Relevance of resource scarcity risk.
5g. Prijs volatiliteit (Price volatility)	Awareness	AW3	Relevance of price volatility risk.
5h. Geo-politieke spanningen (Geopolitical tensions)	Awareness	AW3	Relevance of geopolitical tension risk.
6. Hoe belangrijk vind je het de volgende strategische risico's relatief gezien vergeleken met 'CRM-leveringsrisico's'? (How important do you consider the following strategic risks compared to 'CRM supply risks'?)	Sense of Urgency	SU 1	All subquestions ask for prioritization of risks
6a. Veranderende marktvraag (Changing market demand)	Sense of Urgency	SU1	Prioritizing CRM vs. market demand risk.
6b. AI (AI)	Sense of Urgency	SU1	Prioritizing CRM vs. AI risk.
6c. Personeelstekort (Staff shortage)	Sense of Urgency	SU1	Prioritizing CRM vs. staff shortage risk.
6d. Economische recessie (Economic recession)	Sense of Urgency	SU1	Prioritizing CRM vs. recession risk.
6e. Netcongestie (Grid congestion)	Sense of Urgency	SU1	Prioritizing CRM vs. grid congestion risk.
6f. Milieuwetgeving (Environmental legislation)	Sense of Urgency	SU1	Prioritizing CRM vs. environmental legislation risk.
7. Kan je de volgende risico's rangschikken van het meest naar minst urgent voor jullie bedrijf? (Can you rank the following risks from most to least urgent for your company?)	Sense of Urgency	SU1	Direct risk ranking by urgency.

Continued on next page

Table 3 – continued from previous page

Question)	Category	Sub-concept Code(s) (from Appendix A)	Explanation
8. Is er binnen jullie organisatie al beleid omtrent CRM? (meerdere antwoorden mogelijk) (Does your organization already have policies regarding CRMs?)	Organizational Strategy	ST2	Existence of CRM-specific strategies.
9. Dit beleid is relevant binnen..... (This policy is relevant within.....)			
9a. de inkoop van (producten met) CRM (the procurement of (products with) CRMs)	Organizational Strategy	ST2	Policy relevance to CRM procurement.
9b. het gebruik van (producten met) CRM (the use of (products with) CRMs)	Organizational Strategy	ST2	Policy relevance to CRM utilization.
10. Het verminderen van CRM binnen onze waardeketen zie ik als: (I see reducing CRMs in our value chain as:)	Sense of Urgency	SU4, SU5	Perception of CRM reduction: solution awareness, opportunity, willingness to act.
11. Hoe goed voorbereid acht je je organisatie op dit moment op .... (How well prepared do you currently consider your organization for....)			
11a. plotselinge significante verstoringen in de CRM-aanvoer? (sudden significant disruptions in CRM supply?)	Organizational Strategy	ST2, ST4	Preparedness for sudden disruptions; strategic stance.
11b. toekomstige langdurige tekorten in CRM-aanvoer? (future long-term shortages in CRM supply?)	Organizational Strategy	ST2, ST4	Preparedness for long-term shortages; strategic stance.
11c. CRM prijs-volatiliteit? (CRM price volatility?)	Organizational Strategy	ST2, ST4	Preparedness for price volatility; strategic stance.
12. Is er iets specifiek wat je hoopt mee te nemen uit de workshop? (Is there anything specific you hope to take away from the workshop?)	Tool Acceptance	CT1	Expected utility/outcomes from the workshop.

## D. Scenario 1: Innovatieve samenwerking

### Scenario 1: Hoog innovatie – Laag nationalisme

#### Samenvatting

Dit is het meest optimistische scenario, waarbij wereldwijde handel niet wordt verstoord en er tegelijk vol wordt ingezet op innovaties om *Critical Raw Materials* (CRM) te recyclen. Door verminderde afhankelijkheid zijn exportrestricties minder effectief, waardoor er meer wordt ingezet op onderlinge samenwerking.

Dit scenario kenmerkt zich door een combinatie van snelle technologische innovatie op het gebied van substitutie en recycling, samen met een relatief open en op samenwerking gerichte internationale handel in kritieke grondstoffen (KGs). De eerste exportrestricties worden niet opgevolgd en nieuwe samenwerkingsverbanden worden aangegaan. Dit leidt tot een vermindering van de afhankelijkheid van traditionele KG-leveranciers, waaronder China, voor de Nederlandse industrie.

Vanaf 2025 greep de EU de acute CRM-crisis aan als katalysator voor innovatie. Onder leiding van het *Critical Materials Act*-programma werden miljarden geïnvesteerd in substitutietechnologieën, recyclingcapaciteit en nieuwe raffinagetechnieken. Binnen recordtijd werd succes geboekt: hafnium werd succesvol vervangen door alternatieve legeringen in elektronica; recycling van neodymium uit afgedankte windturbines werd mainstream.

#### Kernpunten

- **Hoge leveringszekerheid:** Materialen zijn goed beschikbaar. Substituten en gerecyclede grondstoffen zorgen voor grotere diversiteit op de markt.
- **Lage prijsvolatiliteit:** Een stabiele internationale handel draagt bij aan voorspelbare prijzen.
- **Efficiënte projecten:** De sector kan projecten efficiënter plannen en uitvoeren met minder risico op vertragingen door materiaalschaarste.
- **Nieuwe kansen:** Er ontstaan nieuwe markten en mogelijkheden voor bedrijven gespecialiseerd in alternatieve materialen en recycling.
- **Gestroomlijnde samenwerking:** Innovatie en samenwerking binnen de sector worden gestimuleerd.
- **Minder geopolitieke kwetsbaarheid:** Strategisch is de sector minder gevoelig voor internationale spanningen.

#### Tijdslijn 2025–2028

- **2025:** De-escalatie handelsoorlog, China benadrukt belang samenwerking met Europa. Europese Unie lanceert spoedprogramma's zoals het *Critical Materials Innovation Pact*. Private investeringen in alternatieve materialen verdrievoudigen. Geopolitieke spanningen nemen af, escalatie handelsoorlog blijft uit. COP30 is een groot succes, belang van CRM en wereldwijde samenwerking wordt benadrukt.
- **2026:** Nieuwe recyclingfabrieken voor neodymium en gallium openen in Nederland en Duitsland. REE-fabriek in België heropend. Kennisuitwisseling en investeringen zorgen dat de circulaire economie onverwacht groeit.
- **2027:** Doorbraken in substitutie, bijvoorbeeld het gebruik van aluminiumlegeringen in plaats van beryllium in elektronica.
- **2028:** Afhankelijkheid van China is niet verdwenen, maar alternatieven en voorraden zijn beschikbaar. Doelen in de CRMA lijken overschreden te worden.

## E. Scenario 1 translated

### Scenario 1: Innovative Collaboration – High Innovation, Low Nationalism

#### Summary

This is the most optimistic scenario, where global trade remains undisrupted and strong efforts are made to innovate in the recycling of *Critical Raw Materials* (CRMs). Reduced dependence makes export restrictions less effective, fostering increased international collaboration.

This scenario is characterized by rapid technological innovation in substitution and recycling, combined with relatively open and collaborative international trade in critical raw materials (CRMs). Initial export restrictions are not followed up, and new partnerships are formed. This reduces dependency on traditional CRM suppliers, including China, for the Dutch industry.

From 2025 onwards, the EU seized the acute CRM crisis as a catalyst for innovation. Under the leadership of the *Critical Materials Act* programme, billions were invested in substitution technologies, recycling capacity, and new refining techniques. Success was achieved at record speed: hafnium was successfully replaced by alternative alloys in electronics; recycling of neodymium from decommissioned wind turbines became mainstream.

#### Key Points

- **High supply security:** Materials are readily available. Substitutes and recycled raw materials provide greater market diversity.
- **Low price volatility:** Stable international trade contributes to predictable prices.
- **Efficient projects:** The sector can plan and execute projects more efficiently, with less risk of delays due to material shortages.
- **New opportunities:** New markets and opportunities emerge for companies specialising in alternative materials and recycling.
- **Streamlined collaboration:** Innovation and collaboration within the sector are stimulated.
- **Reduced geopolitical vulnerability:** Strategically, the sector is less sensitive to international tensions.

#### Timeline 2025–2028

- **2025:** De-escalation of the trade war, China emphasizes cooperation with Europe. The European Union launches emergency programmes such as the *Critical Materials Innovation Pact*. Private investments in alternative materials triple. Geopolitical tensions ease, escalation of the trade war is avoided. COP30 is a major success, highlighting the importance of CRM and global cooperation.
- **2026:** New recycling plants for neodymium and gallium open in the Netherlands and Germany. The REE plant in Belgium is reopened. Knowledge sharing and investments cause the circular economy to grow unexpectedly fast.
- **2027:** Breakthroughs in substitution, for example, the use of aluminium alloys instead of beryllium in electronics.
- **2028:** Dependency on China has not disappeared, but alternatives and stockpiles are available. Targets set in the CRMA appear to be exceeded.

## F. Scenario 2: Fort Europa

### Hoge innovatie – Hoog nationalisme

Terugblik vanuit 2028

De handelsoorlog escaleert volledig: alle export uit China is onderhevig aan hoge tarieven en restricties. Echter, de exportrestricties op *Critical Raw Materials* (CRM) vanuit China vormen een wake-up call voor Europa en de Nederlandse overheid. Om de afhankelijkheid zo snel mogelijk te verminderen, richtte Europa onder leiding van Duitsland, Frankrijk en Zweden een *Critical Materials Shield* op. Strikte exportrestricties werden beantwoord met Europese zelfvoorziening.

Grootschalige raffinaderijen voor lithium, kobalt en zeldzame aardmetalen werden versneld gebouwd. Daarnaast betaalden investeringen en overeenkomsten met andere landen, zoals Australië, Namibië, Argentinië en Zuid-Afrika, zich uit in een diverse aanvoerketen van materialen.

**Snelle technologische innovatie:** zoals synthetische alternatieven voor grafiet en verbeterde recycling van gallium. Door samenwerkingen en investeringen kwamen fabrieken, zoals de Solvay REE in België, versneld in operatie.

Desalniettemin zijn er tijdens de opbouw van Europese productie regelmatig tekorten van materialen, resulterend in prijsschommelingen en lange levertijden.

Tijdslijn 2025–2028

- **2025:** Verdere escalatie van de handelsoorlog. China en andere landen voeren steeds vaker en strengere exportrestricties in voor een breed scala aan kritieke grondstoffen. Na de CRM-crisis kondigt Europa het *European Materials Sovereignty Initiative* aan. Subsidies voor raffinage, mijnbouw en recycling nemen explosief toe.
- **2026:** Aanzienlijke verstoringen en prijsschommelingen in materiaaltoevoer. Eerste Europese fabriek voor synthetische REE-alternatieven opent in België.
- **2027:** Circulaire economie: 40% van de CRM-vraag in Europa wordt via eigen recycling afgedekt.
- **2028:** Zelfvoorziening bereikt 70%; invoer uit China daalt naar 15% van de behoefte.



## G. Scenario 2 translated

### High Innovation – High Nationalism

#### Retrospective from 2028

The trade war escalates fully: all exports from China are subject to high tariffs and restrictions. However, the export restrictions on *Critical Raw Materials* (CRMs) from China serve as a wake-up call for Europe and the Dutch government. To reduce dependence as quickly as possible, Europe—led by Germany, France, and Sweden—establishes a *Critical Materials Shield*. Strict export controls are met with a push for European self-sufficiency.

Large-scale refineries for lithium, cobalt, and rare earth elements are rapidly constructed. Additionally, investments and agreements with other countries—such as Australia, Namibia, Argentina, and South Africa—pay off in the form of a more diversified supply chain.

**Rapid technological innovation:** includes synthetic alternatives to graphite and improved recycling of gallium. Through collaborations and investments, plants such as the Solvay REE facility in Belgium come online faster than expected.

Nevertheless, during the buildup of European production capacity, material shortages regularly occur, resulting in price fluctuations and long lead times.

#### Timeline 2025–2028

- **2025:** Further escalation of the trade war. China and other countries increasingly introduce strict export restrictions on a wide range of critical raw materials. Following the CRM crisis, Europe announces the *European Materials Sovereignty Initiative*. Subsidies for refining, mining, and recycling surge dramatically.
- **2026:** Significant disruptions and price volatility in material supply. The first European factory for synthetic REE alternatives opens in Belgium.
- **2027:** Circular economy milestone: 40% of CRM demand in Europe is met through domestic recycling.
- **2028:** Self-sufficiency reaches 70%; imports from China drop to 15% of total demand.

## H. Scenario 3: Hert in de koplampen

### Lage innovatie – Hoog nationalisme

#### Introductie

*Hert in de koplampen*: we zien de afhankelijkheid en grondstoftekorten aankomen, maar in plaats van te handelen verstijft Europa. Dit scenario schetst de meest kwetsbare toekomst voor de Nederlandse industrie. Hoewel de wereldwijde beschikbaarheid van kritieke grondstoffen ernstig onder druk staat als gevolg van toenemende geopolitieke spanningen, blijven ontwikkelingen en externe samenwerkingen uit door gebrek aan politieke daadkracht.

Dit resulteert in structureel lage leveringszekerheid, frequente tekorten en extreme prijsvolatiliteit. Niet alleen grondstoffen, maar ook producten waarin deze verwerkt zijn (zoals chips en zonnepanelen) ondervinden disrupties in de toevoer. Technologische innovatie, met name op het gebied van recycling en substitutie, blijkt onvoldoende snel om de acute problemen van materiaalschaarste op te lossen. Dit leidt tot ernstige belemmeringen voor projectplanning en -uitvoering, en zelfs het voortbestaan van bedrijven wordt bedreigd. Bedrijven die willen innoveren lopen tegen een breed scala aan uitdagingen aan, zoals netcongestie, milieuwetgeving en personeelstekorten. Tussen Europese landen is weinig samenwerking door een toegenomen nationalistische blik.

#### Terugblik vanuit 2028

In 2026 escaleerde het conflict rondom Taiwan. China verscherpte exportrestricties op strategische materialen zoals antimoon, fluorspar en lichte zeldzame aardmetalen (Light REE), maar ook op productgroepen als zonnepanelen, chips en magneten. In een poging de energievoorziening van Amerika te ondermijnen, kwamen ook de transitie-ambities van Europa in het nauw.

Nieuwe handelsblokken ontstonden: BRICS+ landen beperkten hun CRM-export richting het Westen. Economisch nationalisme creëerde een domino-effect; interne samenwerking in Europa stagneerde.

Technologische innovatie kon de acute tekorten niet bijbenen. Recycling van CRM bleef marginaal door gebrek aan schaalgrootte en kostenproblemen. Europese voorraden slonken snel. Doelstellingen uit programma's zoals de CRMA werden uitgesteld; economische urgentie domineerde de beleidsagenda.

#### Tijdslijn 2025–2028

- **2025:** Na escalatie van de handelsoorlog verslechteren de banden met China. In reactie blokkeert China de export van lithium, kobalt en antimoon, evenals chips, magneten en zonnepanelen. De reactie van de EU en Nederland blijft beperkt tot diplomatieke inspanningen en het zoeken naar alternatieve leveranciers. Deze pogingen hebben weinig direct effect op de algemene leveringszekerheid.
- **2026:** WTO-onderhandelingen over grondstoffenhandel mislukken. Nieuwe Aziatische handelsblokken ontstaan, de relaties tussen het Westen en Azië bekoelen. De situatie rondom Taiwan escaleert; oorlog lijkt aanstaande.
- **2027:** China belegert Taiwan. Amerika en Europa grijpen niet in, maar alle officiële handelsstromen worden verbroken. Europa raakt zwaar afhankelijk van contracten met andere landen en secundaire bronnen (zoals e-waste), maar recycling blijft ver achter door trage opschaling. De prijzen voor CRM – vooral REE zoals dysprosium en praseodymium – vertienvoudigen. Europese industrieën ondervinden massale productievertragingen.
- **2028:** Voorraadbuffers raken uitgeput. Recycling komt vertraagd op gang maar kan pas rond 2035 aan de vraag voldoen. CRMA-doelstellingen worden definitief afgeschaft. Grote economische afhankelijkheid van China domineert de markt.

## I. Scenario 3 translated

### Low Innovation – High Nationalism

#### Introduction

*Deer in the headlights:* we see the dependency and resource shortages approaching, but instead of acting, Europe freezes. This scenario outlines the most vulnerable future for the Dutch industry. While the global availability of critical raw materials is under severe pressure due to rising geopolitical tensions, developments and external collaborations fail to materialize due to a lack of political decisiveness.

This results in structurally low supply security, frequent shortages, and extreme price volatility. Not only raw materials but also products in which they are embedded (such as chips and solar panels) suffer from supply disruptions. Technological innovation—particularly in recycling and substitution—proves too slow to resolve acute material scarcity. This leads to severe barriers for project planning and execution, with the very survival of companies being threatened. Companies that want to innovate face a wide range of challenges, including grid congestion, environmental regulations, and labor shortages. There is little cooperation between European countries due to an increasingly nationalist outlook.

#### Retrospective from 2028

In 2026, the Taiwan conflict escalated. China tightened export restrictions on strategic materials such as antimony, fluorspar, and light rare earth elements (Light REEs), as well as on product categories like solar panels, chips, and magnets. In an attempt to undermine America's energy supply, Europe's energy transition ambitions were also compromised.

New trade blocs emerged: BRICS+ countries limited CRM exports to the West. Economic nationalism created a domino effect; internal cooperation within Europe stalled.

Technological innovation could not keep up with the acute shortages. CRM recycling remained marginal due to lack of scale and cost barriers. European reserves depleted rapidly. Goals from initiatives such as the CRMA were hollowed out; economic urgency dominated the policy agenda.

#### Timeline 2025–2028

- **2025:** After the escalation of the trade war, relations with China deteriorate. In response, China blocks exports of lithium, cobalt, and antimony, as well as chips, magnets, and solar panels. The EU and the Netherlands respond only with diplomatic efforts and attempts to find alternative suppliers. These efforts have little immediate effect on overall supply security.
- **2026:** WTO negotiations on raw materials trade collapse. New Asian trade blocs emerge, and relations between the West and Asia cool. The situation around Taiwan escalates; war appears imminent.
- **2027:** China besieges Taiwan. The US and Europe do not intervene, but all official trade flows are cut off. Europe becomes heavily dependent on contracts with other countries and secondary sources (such as e-waste), but recycling significantly lags due to slow scaling. Prices for CRMs—especially REEs like dysprosium and praseodymium—increase tenfold. European industries experience massive production delays.
- **2028:** Stockpiles are exhausted. Recycling starts to ramp up but will not meet demand until around 2035. CRMA targets are officially abandoned. Heavy economic dependence on China dominates the market.

## J. Scenario 4: Vooruitschuifpolitiek

### Lage innovatie – Laag nationalisme

Terugblik vanuit 2028

In dit scenario blijft escalatie van de handelsoorlog uit, waarna eerdere handelsbeperkingen worden versoepeld. Hierdoor verliest het onderwerp CRM urgentie tegenover andere politieke onderwerpen, zoals de afhankelijkheid van Amerikaanse IT-infrastructuur. China blijft vol inzetten op batterijtechnologie en duurzame energiebronnen waardoor duurzaamheidsdoelen in zicht blijven.

Echter blijft Europa achter op het gebied van innovatie, waardoor de afhankelijkheid van China alleen maar verder toeneemt. Recycling in Europa komt niet van de grond, en initiatieven die eerder werden gepland kunnen niet concurreren met Chinese bedrijven die wel staatssteun ontvangen.

De wereldwijde politieke situatie blijft relatief stabiel, met beperkte grootschalige verstoringen in de internationale handel in kritieke grondstoffen. De situatie in China blijft stabiel; afhankelijkheid van Taiwan voor nieuwe generatie chips wordt te groot geacht om militaire interventie te laten plaatsvinden.

Hoge rentestanden en lage investeringsbereidheid verlamden R&D. Recycling-initiatieven en substitutietechnologieën blijven steken in pilots. Doelstellingen in de CRMA worden gedempt en uitgesteld.

Tijdslijn 2025–2028

- **2025:** De-escalatie van de handelsoorlog. China kondigt een groot nieuw overheidspakket aan voor duurzame energie. Onder deze investeringen vallen echter ook grote overnames in CRM-supplyketens wereldwijd.
- **2026:** Investerings in R&D in Europa vallen stil door financiële krapte; nieuwe recycling-pilots lopen vast. Doelstellingen in de CRMA worden afgezwakt.
- **2027:** De Europese Unie en Nederland vertrouwen voornamelijk op diplomatieke inspanningen en internationale samenwerking om potentiële grootschalige supplydisrupties te voorkomen. Krapte op de energiemarkt maakt nieuwe recycling- en productielocaties in Nederland extreem onaantrekkelijk.
- **2028:** Door innovatie worden bepaalde recyclingtechnieken minder energie-intensief. Echter is deze opkomst erg traag; doelstellingen voor 2030 worden afgezwakt en verschoven naar 2033.

## K. Scenario 4 translated

### Low Innovation – Low Nationalism

#### Retrospective from 2028

In this scenario, the trade war does not escalate, and previous trade restrictions are eased. As a result, the topic of CRMs loses urgency compared to other political issues, such as dependency on U.S. IT infrastructure. China continues to focus heavily on battery technology and renewable energy, keeping sustainability goals within reach.

However, Europe falls behind in innovation, further increasing its dependence on China. Recycling in Europe fails to take off, and earlier planned initiatives cannot compete with Chinese companies that receive state support.

The global political situation remains relatively stable, with limited large-scale disruptions in the international trade of critical raw materials. The situation in China remains calm; dependence on Taiwan for next-generation chips is deemed too great for military intervention to occur.

High interest rates and low investment appetite paralyze R&D. Recycling initiatives and substitution technologies stall in pilot phases. The goals of the CRMA are softened and delayed.

#### Timeline 2025–2028

- **2025:** De-escalation of the trade war. China announces a major new government package for renewable energy. These investments also include major acquisitions across global CRM supply chains.
- **2026:** R&D investments in Europe come to a halt due to financial constraints; new recycling pilots stall. CRMA targets are weakened.
- **2027:** The European Union and the Netherlands primarily rely on diplomatic efforts and international cooperation to avoid potential large-scale supply disruptions. Tight energy markets make new recycling and production facilities in the Netherlands extremely unattractive.
- **2028:** Technological innovation makes some recycling techniques less energy-intensive. However, progress is very slow; 2030 targets are softened and postponed to 2033.

## L. Worksheet

<b>Scenario:</b>	
<b>Risico's</b>	<b>Mitigerende maatregelen</b>
<b>Kansen</b>	<b>Versterkende maatregelen</b>

## M. Worksheet Backside

**Werkblad voor maatregel .....****Doel van de maatregel****Vragen die nog beantwoord moeten worden**

- 1.
- 2.
- 3.

**Door wie?**

- 1.
- 2.
- 3.

**Tijdslijn**

Nu

**Eerste stappen die gezet moeten worden**

- 1.
- 2.
- 3.

## N. Proxy company for workshop

### Omschrijving:

Innovatec Installaties B.V. is een middelgroot, toonaangevend installatietechniekbedrijf gespecialiseerd in het ontwerpen, installeren en onderhouden van duurzame en slimme technische installaties voor zowel de utiliteitsbouw (kantoren, scholen, zorginstellingen) als de luxere woningbouw. Ze richten zich sterk op energie-efficiëntie, hernieuwbare energie en gebouwautomatisering. Hun projecten variëren van complete nieuwbouwinstallaties tot grootschalige renovaties en langlopende onderhoudscontracten. Ze staan bekend om hun innovatieve aanpak en kwalitatief hoogwaardige uitvoering.

### Materialen in de waardeketen (voorbeelden):

1. **Koper:** Essentieel voor elektrische bedrading, leidingen in warmtepompsystemen en HVAC, componenten in elektromotoren en transformatoren.
2. **Aluminium:** Gebruikt voor frames van zonnepanelen, behuizingen van apparatuur, sommige leidingsoorten en warmtewisselaars.
3. **Staal (incl. roestvast staal):** Voor constructiedelen, bevestigingsmaterialen, grotere leidingen, behuizingen van grotere apparaten (CV-ketels, ventilatie-units).
4. **Zeldzame aardmetalen (ZAM's):**
  - Neodymium, Dysprosium: In permanente magneten voor hoogefficiënte elektromotoren (bijv. in warmtepompen, ventilatiesystemen).
  - Indium, Gallium: In sommige typen zonnecellen (dunne-film) en LED-verlichting.
5. **Lithium & Kobalt:** In batterijen voor energieopslagsystemen (gekoppeld aan zonnepanelen) en noodstroomvoorzieningen.
6. **Silicium:** Basisgrondstof voor zonnecellen en halfgeleiders in elektronische componenten (sensoren, regeltechniek).
7. **Kunststoffen (divers):** Voor isolatiemateriaal (kabels, leidingen), behuizingen, buizen.
8. **Tin:** Voor soldeer in elektronische circuits.

### Hoe komen ze aan deze materialen?

Innovatec koopt zelden de ruwe grondstoffen zelf. Ze kopen voornamelijk:

- *Geassembleerde producten:* Zonnepanelen, warmtepompen, omvormers, sensoren, schakelkasten, LED-armaturen, batterijopslagsystemen. Deze worden ingekocht bij fabrikanten of gespecialiseerde groothandels (vaak internationaal, met productieketens diep in Azië of andere delen van de wereld).
- *Componenten en halffabricaten:* Kabels, leidingen, montagemateriaal, specifieke elektronische modules. Deze komen van gespecialiseerde toeleveranciers en groothandels.

De afhankelijkheid van kritieke grondstoffen zit dus vooral **indirect** in de ingekochte producten en componenten. Ze hebben beperkt zicht op de oorsprong van de daadwerkelijke grondstoffen in die producten.

## 6 Verschillende Functies voor het Rollenspel

### 1. Functie: Algemeen Directeur (CEO) – Dhr. Van den Berg

- **Verantwoordelijkheden:** Eindverantwoordelijk voor de strategie, winstgevendheid, continuïteit en reputatie van Innovatec.
- **CRM-perspectief:** Bezorgd over prijsstijgingen en leveringsonzekerheid die invloed hebben op winstmarges, projectuitvoering, concurrentiepositie en groeistrategie.

### 2. Functie: Hoofd Inkoop – Mevr. Janssen

- **Verantwoordelijkheden:** Selectie van leveranciers, onderhandelingen, voorraadbeheer.
- **CRM-perspectief:** Voelt prijsvolatiliteit en leveringsproblemen direct. Overweegt alternatieven, spreiding van risico's, langetermijncontracten en voorraadstrategieën.

### 3. Functie: Hoofd Engineering & Ontwerp – Dhr. El Amrani

- **Verantwoordelijkheden:** Technisch ontwerp, materiaal- en componentselectie, innovatie.



- **CRM-perspectief:** Onderzoekt alternatieve materialen en modulair ontwerp om afhankelijkheid van CRMs te reduceren.

#### **4. Functie: Projectleider Grote Projecten – Mevr. De Wit**

- **Verantwoordelijkheden:** Leiding over uitvoering van grote installaties, klantcontact, budgetbewaking.
- **CRM-perspectief:** Vreest voor projectvertragingen en boetes door ontbrekende onderdelen.

#### **5. Functie: Sales Manager – Dhr. Pietersen**

- **Verantwoordelijkheden:** Nieuwe opdrachten binnenhalen, relatiebeheer, offertes opstellen.
- **CRM-perspectief:** Moeilijkheden met het offreren van prijzen op lange termijn. Zorgen over duurzame beloftes en concurrentiepositie.

#### **6. Functie: Manager Duurzaamheid & Compliance – Mevr. Singh**

- **Verantwoordelijkheden:** Voldoen aan wet- en regelgeving, stimuleren van duurzaam ondernemen en ethische sourcing.
- **CRM-perspectief:** Bezorgd over mijnbouwomstandigheden, circulariteit en CO<sub>2</sub>-impact van de keten. Ziet kansen in de circulaire economie.

## O. Proxy Company for workshop translated

### Description:

Innovatec Installations B.V. is a medium-sized, leading installation technology company specializing in the design, installation, and maintenance of sustainable and smart technical systems for both commercial buildings (offices, schools, healthcare institutions) and high-end residential construction. Their focus lies on energy efficiency, renewable energy, and building automation. Projects range from complete new-build installations to large-scale renovations and long-term maintenance contracts. The company is known for its innovative approach and high-quality execution.

### Materials in the value chain (examples):

1. **Copper:** Essential for electrical wiring, piping in heat pump systems and HVAC, components in electric motors and transformers.
2. **Aluminum:** Used for solar panel frames, equipment casings, certain piping types, and heat exchangers.
3. **Steel (incl. stainless steel):** For structural components, mounting hardware, large pipes, and casings of larger devices (boilers, ventilation units).
4. **Rare Earth Elements (REEs):**
  - Neodymium, Dysprosium: In permanent magnets for high-efficiency electric motors (e.g., in heat pumps and ventilation systems).
  - Indium, Gallium: In certain types of solar cells (thin-film) and LED lighting.
5. **Lithium & Cobalt:** In batteries for energy storage systems (coupled to solar panels) and emergency power supplies.
6. **Silicon:** Base material for solar cells and semiconductors in electronic components (sensors, control systems).
7. **Plastics (various):** For insulation (cables, piping), housings, conduits.
8. **Tin:** Used for solder in electronic circuits.

### How do they acquire these materials?

Innovatec rarely purchases raw materials directly. They primarily buy:

- *Assembled products:* Solar panels, heat pumps, inverters, sensors, control cabinets, LED fixtures, battery storage systems. These are purchased from manufacturers or specialized wholesalers (often internationally, with supply chains deep into Asia or other global regions).
- *Components and semi-finished products:* Cables, pipes, mounting materials, specific electronic modules. These come from specialized suppliers and wholesalers.

Their dependence on critical raw materials is therefore mainly **indirect**, embedded in the purchased products and components. They have limited insight into the actual origin of the raw materials in those products.

## 6 Distinct Roles for the Role-Play Exercise

### 1. Role: General Director (CEO) – Mr. Van den Berg

- **Responsibilities:** Ultimately responsible for strategy, profitability, continuity, and the reputation of Innovatec.
- **CRM Perspective:** Concerned about rising prices and supply uncertainties impacting profit margins, project execution, competitive position, and growth strategy.

### 2. Role: Head of Procurement – Ms. Janssen

- **Responsibilities:** Supplier selection, negotiations, inventory management.
- **CRM Perspective:** Directly experiences price volatility and supply issues. Considers alternatives, risk diversification, long-term contracts, and inventory strategies.

### 3. Role: Head of Engineering & Design – Mr. El Amrani

- **Responsibilities:** Technical design, material and component selection, innovation.

- **CRM Perspective:** Investigates alternative materials and modular design to reduce CRM dependence.

**4. Role: Project Manager for Large Projects – Ms. De Wit**

- **Responsibilities:** Oversees implementation of large-scale installations, client relations, and budget monitoring.
- **CRM Perspective:** Concerned about project delays and penalties due to missing components.

**5. Role: Sales Manager – Mr. Pietersen**

- **Responsibilities:** Acquiring new projects, client management, drafting proposals.
- **CRM Perspective:** Difficulty offering long-term price guarantees. Worries about sustainable promises and competitive positioning.

**6. Role: Sustainability & Compliance Manager – Ms. Singh**

- **Responsibilities:** Ensuring regulatory compliance, promoting sustainable business practices, and ethical sourcing.
- **CRM Perspective:** Concerned about mining conditions, circularity, and CO<sub>2</sub> impact of the supply chain. Sees opportunities in the circular economy.

## P. Outcomes workshop

Fortress Europe	Dear in headlights	Delay politics	Innovation Shift
<b>Risks</b>			
- Not deliverable ☒ can't serve customers	- Scarcity at product level	- Dependency on third-country knowledge	- Ownership loss / weaker competitiveness
- No product delivery	- Permanently high prices	- Poor investment climate	- Complexity in implementing COP agreements
- Margin loss due to price spikes	- Increased delivery times	- Material cost	- Shortage of resources and people
<b>Opportunities</b>			
+ Competitive advantage via partners + stock	+ Innovation under pressure	+ First-mover advantage	+ Few disruptions
+ Flexibility in finding alternatives	+ Global network becomes key	+ Growing markets: recycling/software	+ New business models
+ Higher turnover / more margin	+ Forced choices (focus)	+ Design based on raw materials	+ Increased insight in sector
+ Market shift			+ Role in circularity/alternatives

Table 4: Perceived risks and opportunities per scenario from the CRM scenario workshop

**Strategic Directions (cross-scenario):**

- Insight into CRM as organizational and production risk
- Supply chain agreements (sector-wide)
- Building coalitions
- Copying best practices (adoption)
- Innovation planning and structuring
- Lifecycle information exchange and ownership
- Approach to China: focus on circularity