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Securing the Energy Transition: A Comprehensive Exploration of Supply Chain Risks and Effective Mitigation Strategies

Joris van de Sande

Master in Management of Services and Technology

Supervisor:

PhD, Sofia Kalakou. Assistant Professor, ISCTE Instituto Universitário de Lisboa

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Resumo

Países e empresas estão tentando se tornar neutros em carbono até 2050. Para alcançar esse objetivo, a demanda por tecnologias de energia renovável e matérias-primas aumentou significativamente. A maioria dessas matérias-primas críticas é produzida e processada por apenas algumas empresas fora da Europa, frequentemente em ambientes geopoliticamente instáveis. Isso ressalta a crescente necessidade de Gerenciamento de Riscos na Cadeia de Suprimentos e de Aquisições. As empresas avaliam seus fornecedores com base no risco do país, qualidade e estabilidade financeira. A nova Diretiva de Relatórios de Sustentabilidade Corporativa (CSRD) indica que as empresas não só precisam medir suas emissões de carbono, mas também relatar sobre seus fornecedores. Portanto, a sustentabilidade deve ser adicionada aos indicadores de avaliação. Para analisar os riscos, a incorporação de sistemas de alerta precoce, auditorias de fornecedores e o monitoramento da sustentabilidade são vitais. Há uma disponibilidade limitada de tecnologias e materiais sustentáveis, como o aço verde. Além disso, dados inconsistentes de ESG/CSR criam dificuldades na avaliação e gestão da sustentabilidade. Há uma deficiência de financiamento para substituir a infraestrutura existente e desafios para atender aos requisitos técnicos ao mesmo tempo em que se melhora a sustentabilidade. Para superar esses desafios, as empresas terão que criar estratégias eficazes de mitigação. Este estudo destaca que as empresas podem superar esses desafios investindo em inovação, criando circularidade, melhorando a transparência de dados, monitorando a sustentabilidade, diversificando sua cadeia de suprimentos e equilibrando a matriz energética.

Palavras-chave: Gestão de Riscos na Cadeia de Suprimentos, Gestão de Riscos em Compras, Sustentabilidade, Transição Energética, Matérias-primas Críticas.

Classificação JEL: Y40 Dissertações, Q01 Desenvolvimento Sustentável.

Abstract

Countries and companies are trying to become carbon neutral by 2050. To achieve this goal the demand for renewable energy technologies and raw materials has significantly increased. Most of these critical raw materials are produced and processed by only a few companies outside of Europe, often in geopolitical unstable environments. This highlights the increasing need for Supply Chain and Procurement Risk Management.

Companies assess their suppliers on country risk, quality, and financial stability. The new Corporate Sustainability Reporting Directive (CSRD) indicates that companies not only have to measure their carbon emissions but also report on their suppliers. Therefore, sustainability should be added to the assessment indicators. To analyze risks incorporating early warning systems, supplier audits, and sustainability tracking are vital. There is limited availability of sustainable technologies and materials, for instance, green steel. Furthermore, inconsistent ESG/CSR data creates difficulties in assessing and managing sustainability. There is a deficiency in funding for replacing existing infrastructure, and challenges to meet the technical requirements while enhancing sustainability. To overcome these challenges companies will have to create effective mitigation strategies. This study highlights that companies can overcome these challenges by Investing in innovation, creating circularity, improving data transparency, tracking sustainability, diversifying their supply chain, and balancing the energy mix.

Keywords: Supply Chain Risk Management, Procurement Risk Management, Sustainability, Energy transition, Critical Raw Materials.

JEL classification: Y40 Dissertations, Q01 Sustainable Development.

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1. Introduction

Countries and companies around the globe actively work to reduce carbon emissions in their supply chain, with the goal of achieving net-zero emissions by 2050. However, achieving those goals is not without obstacles. The COVID-19 pandemic has exposed vulnerabilities and risks across supply chain parties and their operations. According to Linton and Vakil (2022), the world's most significant supply chains with over 12.000 facilities were in quarantine and lockdown areas. This has initiated more research about Supply Chain Risks, mainly focusing on the impact of disruptions and delays caused by various factors such as shutdowns of borders, supplier dependency, supply capacity constraints, exchange rates, and demand and supply volatilities. Chen (2023) Highlighted the need for effective procurement risk management practices and strategic supply chain planning to ensure business continuity. The sector requires stable markets and resilient supply chains to fulfil the growing demand for renewable energy sources. Any disruption in the Supply Chain could have significant consequences for the renewable energy sector (Bettoli et al., 2023). China's dominance in supplying critical raw materials and renewable energy technologies, including windmills, solar panels, batteries, nickel, copper, rare earths, and cobalt, poses opportunities and challenges (Khurshid et al.,2023). Tight Supply Chains and higher input costs push up renewable project costs in many markets (IEA,2021). In their report, the International Energy Agency raised their concerns about the demand and availability of some raw materials. Also, rising prices due to increased demand, the COVID-19 pandemic, and China's tightening of export quotas have raised concerns about the availability of some raw materials.

This topic's practical and academic significance lies in China's role as a primary supplier of critical raw materials and components for renewable energy technologies. Essential minerals like Cobalt, Copper, Lithium, Nickel, and Rare Earth elements are identified as Critical Raw Materials, exhibiting a high risk of supply shortage in the next decade due to demand, concentrated production, and low political-economic stability (European Commission, 2009). This is particularly crucial for climate policies and innovation, where a stable supply is essential. The terms used in the literature are scattered, and we need a better understanding of the different types of risks. Besides, current studies are often theoretical, needing more practical applications for real-world scenarios. This study seeks to bridge this gap by demonstrating practical applications. Hu et al. (2024) call for a more comprehensive understanding of the complexities in the global supply chain for critical materials and energy technologies. As highlighted by the authors, the oversight of the roles played by these multinationals poses a limitation to our understanding of the dynamics within the supply chain network. This research aims to gain a deeper understanding of the challenges and opportunities surrounding these dependencies and identify effective strategies to mitigate associated risks.

The main research question will be: What are the key supply chain risks in the renewable energy sector, and what strategies have been proposed or implemented to mitigate these risks?" To address this question, it is essential to dive into some sub-questions:

RQ1: To what extent is there a dependency on critical materials and components?

The Resource Dependence Theory is introduced, suggesting that organizations strive to reduce dependencies. The negative consequences of high dependency on external partners will be highlighted. Also, the need for a sustainable supply chain transformation is underscored to understand the importance of fostering resilience in supply chains.

RQ2: What are the immediate and long-term risks and vulnerabilities associated with procuring critical inputs for the renewable energy sector, such as rare earth elements, nickel, copper, lithium, and cobalt?

This research question investigates the depth of dependency on critical materials and components in the context of the energy transition. It will touch upon the uncertainties and risks present in Supply Chains and explore the challenges posed by highly interdependent supply chains.

RQ3: What alternative sourcing strategies and supply chain configurations can be developed to mitigate the identified risks and ensure a sustainable supply of essential inputs for renewable energy technologies?

Expert interviews will answer these research questions. The method involves evaluating potential strategies to decrease dependence on suppliers. The question will seek insights into alternative sourcing strategies, such as technology implementation and circular economy principles. The goal is to identify measures to mitigate the identified risks and ensure a sustainable supply of critical raw materials. The literature review will explore key concepts such as supply chain risk management, resource dependence theory, critical raw materials and technologies, dependency on China, and potential risks and mitigation strategies. These concepts provide the foundations for understanding the current challenges and vulnerabilities in global supply chains. The research employs a qualitative methodology, focusing on in-depth insights gathered through interviews with ten experts. This study is designed to explore and address critical issues related to supply chain dynamics and resource dependency in the context of the global supply chains of renewable energy technologies.

A structured risk management framework (ISO 31000, 2009) will be used to guide this analysis. This standard provides a systematic approach for identifying, assessing, and mitigating risks. This framework consists of 5 steps. First, the management context will be established. In this phase, we explain the issue and what we are trying to achieve. Second is the risk assessment. In the ISO 31000 framework, risk assessment consists of three steps. The risk identification., What are the risks that may result in failing the objectives? Second, the risk analysis. What is the effectiveness of management of measures that try to prevent the risks from happening? The third step is the risk evaluation. Here, we try to analyze if action is required to reduce the risk events. Step 5 is the risk treatment step. How should we reduce the risk events and ensure resilience in the value chain?

The remainder of this thesis is structured as follows: Chapter two presents the literature review, highlighting the concept of supply chain risks management, the dependency on China for critical materials and components, and potential risks and mitigation risks are identified. Chapter three outlines the methodology, chapter four discusses the findings of the expert interviews. Chapter five covers the conclusion and limitations, also an overview is given of all the risks and mitigation strategies.

2. Literature review

The global transition towards renewable energy technologies is crucial for mitigating climate change and reducing dependency on fossil fuels. This transition, however, brings to light the complex issue of supply chain dependency, particularly in China, which has emerged as a dominant player in producing critical components and materials for renewable energy technologies. This literature review explores supply chain risk management, the extent of supply chain dependency on China in the context of renewable energy technologies, and its potential implications for global energy security, sustainability, and geopolitical dynamics.

2.1 Supply Chain Risk Management

In literature, Supply Chain risk management is often referred to as managing potential supply chain disruptions (Kim et al.,2014). Bode and Wagner (2015) suggest that disruptions are unintended and unexpected events in the upstream supply chain, inbound logistic network, or the purchasing environment and present a severe threat to the continuation of business operations. Disruption risk is closely linked to supply risk, which is defined as the probability of an incident occurring that is associated with inbound supply, influencing the inability of the buying firm to meet customer demand (Zsidisin & Smith, 2005). Hang et al. (2018) distinguished between operational and disruption risks. Operational risks are related to the coordination of supply chain activities among different parties in the supply chain. Disruption risks encompass losses from unexpected events such as natural disasters or political instability. Fan and Stevenson (2018) suggest that more considerable risks may result in more attention, but managers might overlook those with lower probabilities.

2.1.1 Supply side risks

Procurement risk is part of the umbrella term Supply Chain Risk. According to Hong et al. (2018), Procurement risk management is focused on managing risks by reducing the exposure and uncertainty in the price, lead time, and demand to ensure supply flow with minimum disruption. Many causes of procurement risks are associated with risks originating from the supply side (Hong et al., 2018). For instance, risks related to the incoming material, such as the supply disruption risk and the contractual situation between the supplier and buyer.

The main procurement risk lies in incorrect demand estimation and ineffective coordination between the supply source and internal customer. Typical risks include uncertain customer demand, fluctuating input price of materials, unavailability of supply, and uncertain lead time (Shi et al., 2011). Zsidisin & Smith (2005) state that supply risks include risks stemming from new product development, outbound logistics, and product quality. Supply risks can arise from various factors, such as damage to production facilities, natural disasters, labour-related issues, capacity constraints, inventory challenges, inaccurate forecasts, outsourcing of parts, reliance on third-party logistics, and variability in the production process causing delays (Chopra & Sodhi, 2004; He, 2013). A supply risk typically leads to an increase in quantity or stocking decisions.

One procurement risk originating in supply-side risks is supplier dependence (He, 2013). This has been conceptualized as the degree to which a company acquires raw materials or inputs from one or more suppliers with limited alternative sources available (Halikas et al., 2004). Increasing supplier power and limited choices for switching. Other factors could be supplier concentration, single sourcing, global sourcing, relationship quality with suppliers, information sharing, and trust in suppliers. Understanding the risks associated with procurement helps companies to purchase the suitable materials to be ready and act before problem occurs.

2.1.2 Risk Management Framework

Swierczek (2014) highlights that Procurement Risk Management (PRM) is one of the most crucial issues in SCM. Risks in the primitive interaction between buyer and supplier could have multiple consequences and should be mitigated. The author calls it the "Snowball effect. Halikas et al. (2004) suggest four steps for Supply Chain Risk Management (SCRM). Risk identification, risk assessment, risk management, and risk monitoring are also referred to as ISO 31000 (ISO 31000, 2009). In this framework, the first step is to identify risks and develop a common understanding of future uncertainties. The second step is risk assessment, which means attributing probabilities of risks to happen and their consequences. The third step is to define the risk management actions; the final step is to monitor the risk.

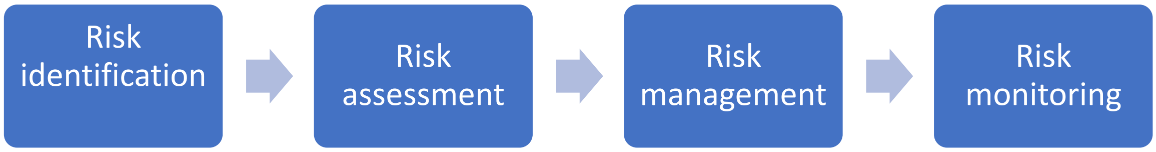

Figure 2-1 Risk Management framework: Based on Halikas et al. (2004)

2.2 Resource dependency

According to the Resource Dependency theory, an organization's need for scarce, external resources creates a dependence on external partners and, thereby, a potential source of adversity (Bode et al., 2015). Companies strategically manage their relationships by forming inter-organizational connections. These relationships exchange knowledge and resources or implement joint problem-solving. This can help to mitigate risk and reliance (Cyert & March 1963).

The resource dependence theory emphasizes acquiring complementary resources from external sources necessary for organizational survival and success (Barringer & Harrison, 2000). This means that organizations seek out to external partners to fill in gaps in the resources they lack but need to thrive. The level of dependence experienced by a firm is influenced by the demand for the resource and the availability of alternative suppliers. A dependence is often mutual and creates an interdependence between actors. Dependence asymmetry measures an organization's ability to rely on a specific business partner, resulting in power imbalances (Davis & Adam Cobb, 2010). Escalating dependencies could disrupt business activities and create uncertainty in resource access (Ivanov & Dolgui, 2020). According to the RBT, firms can create unique and difficult-to-imitate resource bundles by combining their resources. Such relationship-specific capabilities can create sustainable competitive advantages (Dyer & Singh, 1998). Resource dependence and Supply Chain Risk Management highlight the need for coordination when one party lacks control. Companies should employ mitigation strategies to minimize dependence on external parties.

2.3 Critical materials and technologies

Nivard et al. (2024) identified five technologies that are crucial for the energy transition. Solar photovoltaics (PVs), Wind (on and offshore), electric vehicles (EVs), heat pumps, and green hydrogen. These technologies are considered low-carbon technologies and are vital for a sustainable transition. Watari et al. (2019) argue that the transition to these cleaner energy sources will cause a significant increase in resource flows associated with mining activities and could lead to the generation of more mine waste.

Raw material criticality is generally assessed at different levels, mainly at the national economy, industry, technology, or component level. Achzet and Helbig 2013; Erdmann and Graedel 2011; Graedel and Reck 2015; Helbig et al. 2016a; Cimprich et al. 2019). In most raw material assessment studies, the supply disruption assessment is evaluated as the likelihood of an increase in demand, a decrease in supply, or both (Cimprich et al., 2019). Lütkehaus et al. (2021) argued that no common methodology would constitute a standard critical assessment procedure for raw materials. The authors also argue that supply risk is misleading and use supply disruption probability instead. Measuring raw-material criticality is characterized by applying two main dimensions: the supply disruption probability and the system's vulnerability to a supply disruption. Different indicators are being used to assess the technological, geological, economic, political, and environmental factors that influence these two parameters (Lütkehaus et al.,2021). For instance, the supply disruption probability research often looks at the concentration of mining sites in a single or only a few countries, monopolistic characteristics of production/ processing companies, raw material abundance, recyclability, and substitutability (Lütkehaus et al.,2021). The vulnerability of a system often refers to the type and severity of the potential disruption impact.

A review of these studies shows a wide variance of critical raw materials. The International Renewable Energy Agency (IRENA, 2023) concluded that five raw materials are included in most assessment studies. These materials are Cobalt, Copper, Nickel, Lithium, and rare earths (Neodymium and Dysprosium). Watari et al. (2019) argue that nickel, cobalt, and lithium have an enormous potential for adverse environmental impacts. Also, some minerals, specifically steel, copper, and silver, can change natural landscapes. Watari et al.

(2019) emphasize the possibility that the energy transition could adversely impact resource-extraction countries. "It is essential to manage the resources cycle to mitigate mineral availability and reduce adverse impacts associated with mining". Low-carbon technologies, such as coal, can reduce energy flows in the use phase. The authors emphasize the importance of managing copper and rare earth metals such as Nickel, Lithium, and Cobalt. This could include recycling rare materials.

In the literature, the material-energy nexus has emerged to address future resource constraints and assist in facilitating the global transition to low-carbon energy systems. The ME -nexus (Material- to Energy) recognizes the significant demand for clean energy technologies, complementary materials, and material extraction and processing. The production of renewable energy technologies in China has experienced significant growth. China's advancements in renewable energy technologies, such as solar, wind, and batteries, have led to Europe's dependency on Chinese production. China has implemented policies that promote renewable energy through mandates and incentives to support the development of domestic technologies (Lewis, 2014). This has led to a significant increase in production capacities. Europe's reliance on Chinese production raises concerns about supply vulnerabilities. However, China's commitment to renewable energy deployment has significantly improved the capacity and efficiency of renewable energy technologies. Hu et al (2024) state that consuming countries should support producing countries in building renewable energy capacity. This will contribute to optimizing energy-saving technologies and implementing high environmental standards for resource extraction. The authors recognize that fossil fuels not only serve as energy sources but also as material sources. Reducing fossil fuel mining may negatively impact the availability of critical materials for clean energy technologies.

The vulnerability of raw materials is usually described as the availability of substitutes and other abilities to adapt to a changing supply and demand (Lütkehaus et al., 2021). Geographical concentration has been a focal point in studying global supply chains, particularly in the initial stages of material production (Hu et al., 2024). Most studies overlook the roles of multinationals and the risks associated with the later stages of the product cycle. Hu et al. (2024) call for more research on these aspects for a more comprehensive understanding of the complexities in the global supply chain for critical materials and energy technologies. As highlighted by the authors, the oversight of the roles played by these multinationals poses a limitation to our understanding of the dynamics within the supply chain network. In addressing this gap, this study seeks to contribute to a more holistic comprehension of the global supply chain for critical materials and energy technologies by delving into these aspects.

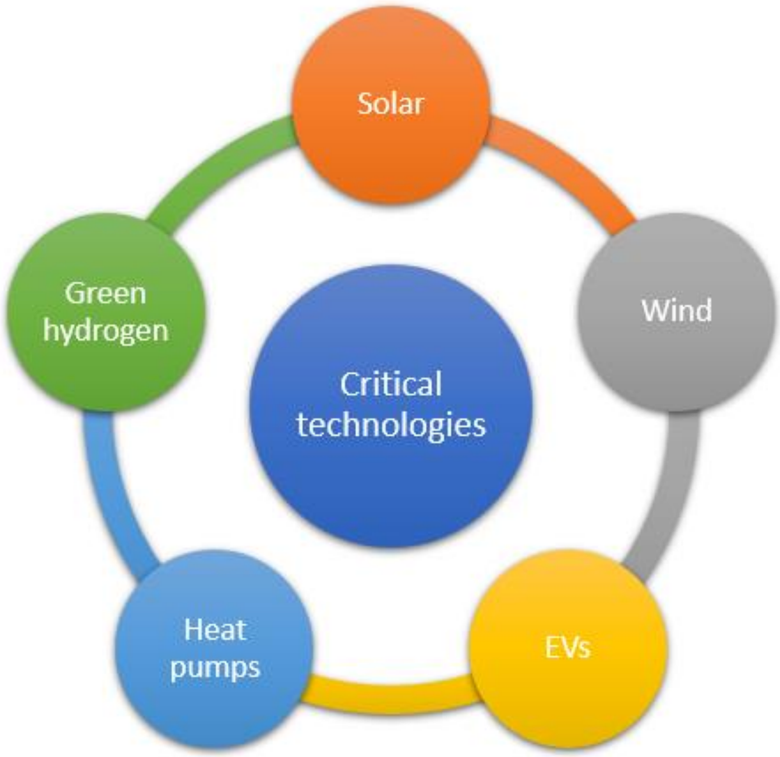

Figure 2-2 Critical technologies. Identified by IRENA (2021)

2.4 Dependency on China

Despite being the world's primary importer of raw or unprocessed materials like nickel, copper, lithium, cobalt, and rare earths, China's influence extends to substantial segments of midstream and downstream capacities for numerous critical materials (Figure 2-2). Often trade statistics only show imports to the last shipping country, concealing the actual origin of materials. Furthermore, mineral commodities from various countries can be embedded within a finished or semi-finished import. This makes it difficult to measure actual reliance.

Koyamparambath et al. (2022) analyzed the supply risk of raw materials used in batteries and compared it with the supply risk of fossil fuels. They observed that the supply disruption risk of raw materials is much higher than fossil fuels because the global distribution of fossil fuel production is more diversified. The recent transition to batteries for electric vehicles has not yet seen the same response to mitigate supply chain risks. This aligns with the recent report published by the International Energy Agency (IEA, 2021). Cobalt is among the metals with the highest supply risks for the EU. The DRC has been the dominant producer since the 1970s, with an increasing share in production until 2012. After 2012, the EU reduced its dependency on imports of Cobalt from DRC. They increased imports from countries with a better Worldwide Governance indicator (WGI-PV score), such as Australia and Canada (Koyamparambath et al, 2022).

Rabe et al. (2017) highlight Europe's dependency on China for critical raw materials for wind and solar energy production. Rare earth elements such as tellurium, gallium, indium, neodymium, and dysprosium are primarily sourced from China, which dominates the global supply.). In 2009, the EU entirely depended on rare earth imports (Bettoli et al., 2023). China accounted for 97% of world rare earths production. Rare earths are essential for manufacturing high-performance magnets in wind turbines and electric vehicle motors (Simandl et al., 2021). China also has a significant presence in the lithium supply chain. This material is crucial for energy storage and EVs.

The formation of the China Rare Earth Group, a state-controlled conglomerate, intensifies concerns over supply chain vulnerabilities (Mitchell & Yu, 2021). The International Renewable Energy Agency (IRENA, 2023) also warns about the vulnerabilities of the global renewable energy supply chain, mainly due to reliance on China for critical materials. According to them, Natural disasters, supply chain bottlenecks, or trade disputes can significantly affect production and deployment. Metals such as aluminum, copper, nickel, tin, and zinc are traded on stock exchanges such as the London Metals Exchange (LME). Many of the EU's critical raw materials, such as cobalt, gallium, indium, and rare earths, are not traded on the LME. Resulting in less transparency and smaller traded volumes compared to base materials (Mitchell & Yu, 2021)

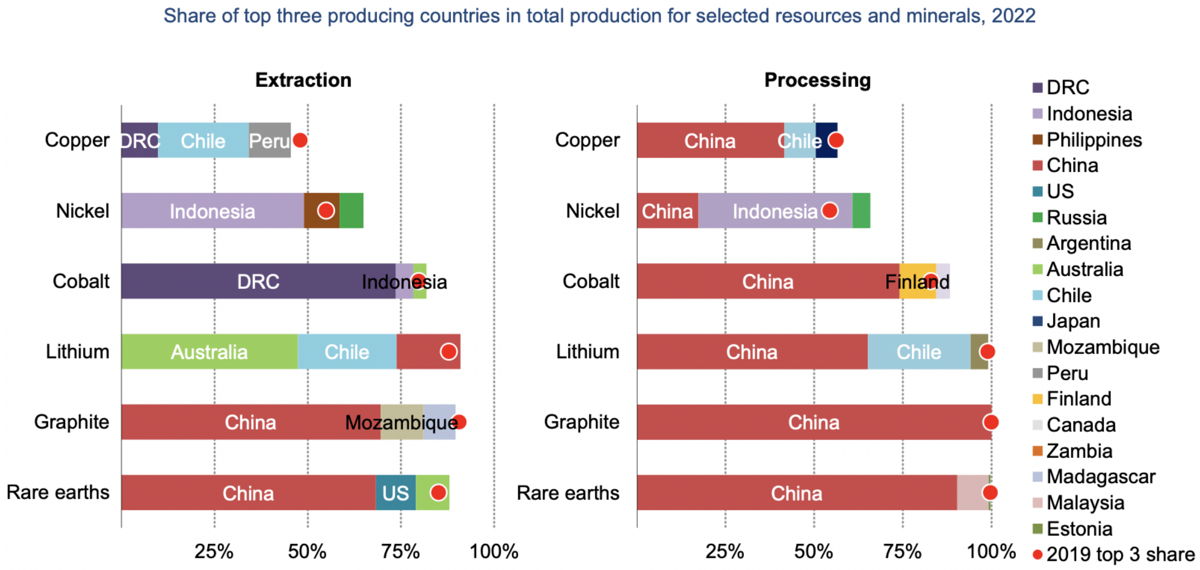

Figure 2-3: Overview of Critical raw materials and location of extraction and processing (IEA, 2021)

Solar Photovoltaics (PV). China's solar PV industry is the world's largest, with a significant share of global cell and PV module production (IEA,2021). The country's ability to produce low-cost PVs has driven the cost of PVs. This has accelerated its adoption in various countries but also raised some concerns. European producers struggle to produce for the exact costs and become too dependent on China's PV production. According to Gan (2023), the global production of solar panels in China has grown from 66% in 2010 to 77% in 2021. This has reduced market share and production capacity for European suppliers. 0,2% of the total world production was produced in Europe in 2021. The rise in Chinese production of solar panels has been accompanied by technological advancements (Hou & Chen, 2023). Gan (2023) highlights that Europe needs strategic planning to ensure a resilient supply chain.

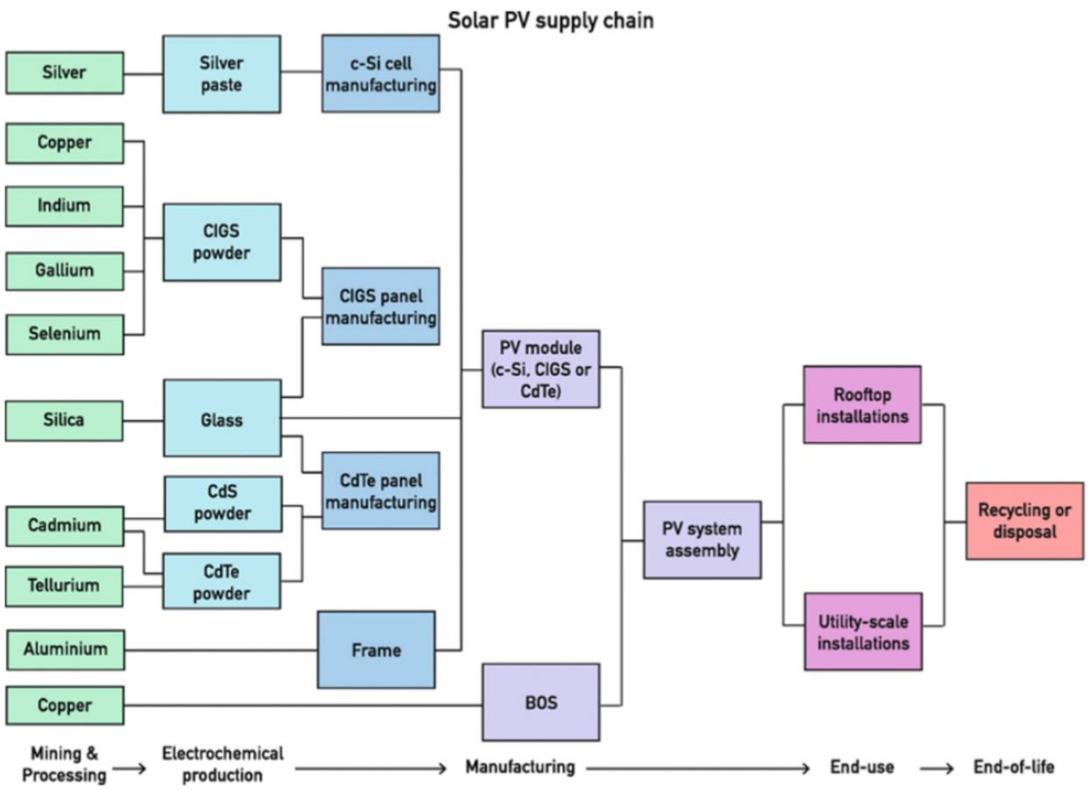

Fig. 3. Overview of solar PV panel supply chain (Giurco et al., 2019).

Figure 2-4: The Supply Chain of Solar PV (Watari et al., 2019)

Wind Turbines. China is also a leading manufacturer of wind turbines and components; manufacturers like Siemens Gamesa, Vestas, and GE have reported significant losses in 2022, partly due to supply chain challenges and competition. Bettoli et al. (2023) warn that these issues could influence global ambitions. Chinese manufacturers may gain market share, leveraging cost competitiveness that could be challenging for developers and policymakers to resist. China's wind power capacity has multiplied, with many investments in manufacturing and developing on and offshore wind farms. Lewis and Wiser (2007) stated the motivations behind a local wind power industry and the different paths that countries have taken. The increasing dominance of Chinese wind power technology has implications for Europe's energy transition. Figure ().. gives an overview of the wind supply chain.

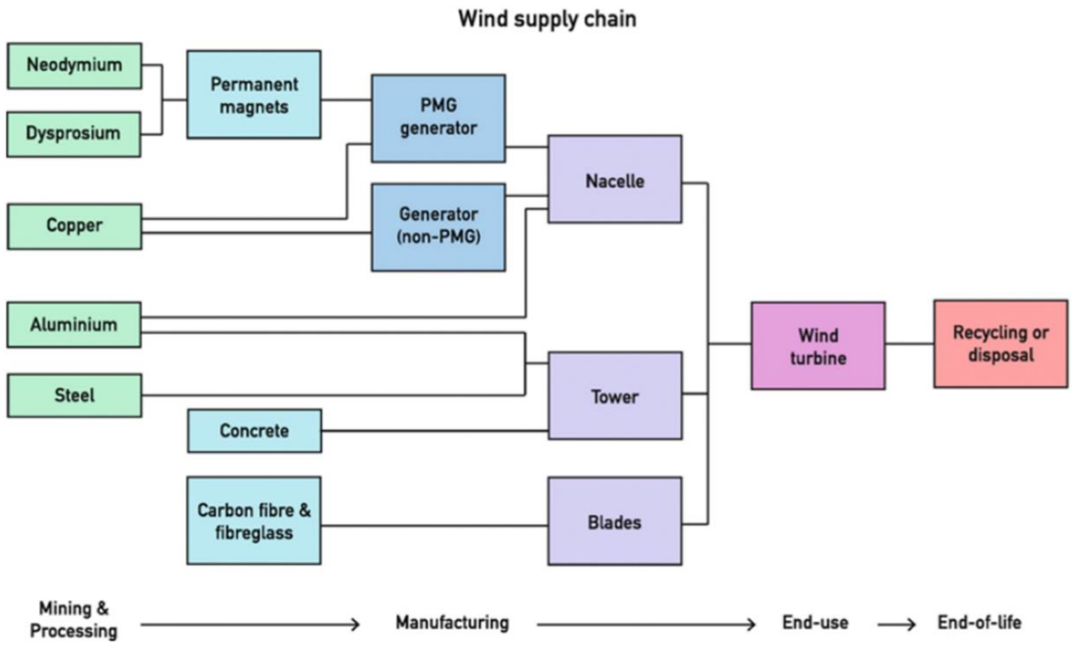

Fig. 5. Overview of wind turbine supply chain (Giurco et al., 2019).

Figure 2-5: The Supply Chain of wind turbines (Watari et al., 2019)

Lithium-ion Batteries. Lithium-ion batteries are crucial for EVs and for energy storage. China controls a significant portion of the global lithium-ion battery supply chain. According to Majzoobi and Khodaei (2017), a mismatch between power supply and demand can lead to power cuts. Therefore, innovation for reliable and stable electricity storage is crucial and has received much focus for investment. Kozlova et al. (2023) discuss the interplay between renewable energy support schemes and capacity mechanisms in the European context. It highlights how states often employ conflicting policies, where renewable energy support aims to decarbonize the energy sector, while capacity mechanisms rely on fossil-fuel-based energy solutions to compensate for the intermittency of renewable energy sources, hindering the energy transition. The EU adopted policies to achieve net zero for mobility. Horizon 2020, an EU innovation program, has allocated a share of its budget to improvements and innovation in energy storage. The EU's strategic action plan on batteries is focused on development and production. (EC, 2019)

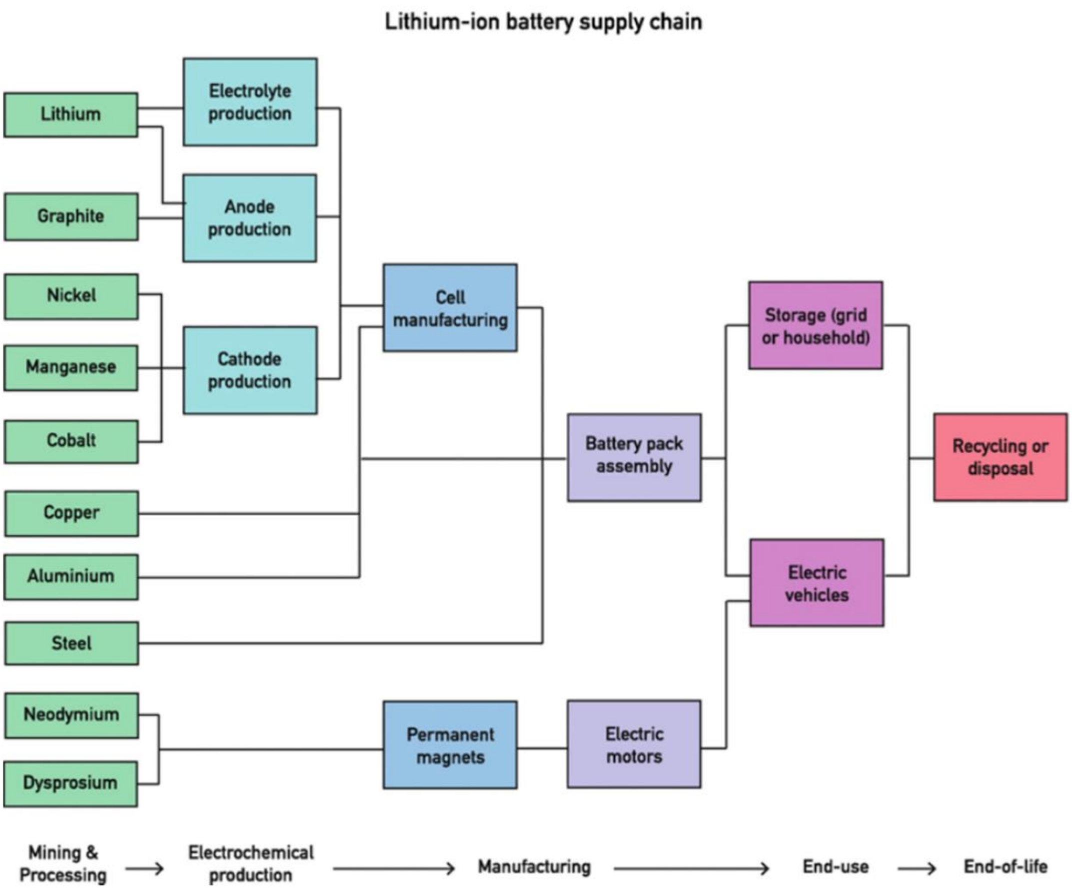

Fig. 1. Overview of lithium-ion battery supply chain (Giurco et al., 2019).

Figure 2-6: The Supply Chain of Lithium-ion batteries. (Watari et al., 2019)

2.5 Supply Chain Risks

Renewable energy technologies and raw materials are essential for a sustainable energy system. The availability and concentration of critical raw materials heavily influence the supply chains for renewable energy technologies. The Supply Chain for these technologies is subject to various risks that can impact their development. Multiple studies have addressed the challenges and opportunities related to supply chain risks of renewable energy technologies and required raw materials. (Jelti et al, 2021) conducted an extensive literature review to identify supply chain trends of renewable energy technologies. The authors highlighted the need for performance improvements to overcome development barriers.

Operational and Technological Risks Baryannis et al. (2019) identify operational and technical performance risks. These include disruptions, delays, system failures, and forecast inaccuracies. These risks can lead to equipment breakdowns, delivery delays, and data integrity issues. Within the renewable energy sector, these risks can have significant consequences. For example, a delay can halt the construction of a wind farm, and system failure in the digital infrastructure can lead to inefficiencies and higher costs.

Investment in mining and extraction is another critical aspect influencing supply chain stability. Achzet and Helbig (2013) note that future capacities and investments are vital for managing resource availability and mitigating risks associated with scarcity and strategic use. Technological advancements increase demand, which can outpace supply and increase prices and shortages (Achzet & Helbig, 2013). Fluctuating commodity prices will also be reflected in production costs, making it challenging to maintain predictability in the cost and the supply chain. Simchi-Levi et al. (2008) contributed that exchange rate fluctuations can affect international and domestic operations, influencing costs and profitability.

Cimprich et al. (2019) incorporated trade risk, logistic restrictions, and resource competition into the risk assessment framework. These risks can be categorized as geopolitical risks. Geopolitical risks encompass regulatory changes, conflict, and trade disputes. These factors can impact operational, tactical, and strategic planning (Simchi-Levi et al., 2008)

Achzet and Helbig (2013) identified 20 indicators to evaluate procurement risks. Country concentration, depletion time, company concentration, recycling potential, byproduct dependency, substitutability, import dependence, exploration degree, production costs of extraction, stock keeping, mine/refinery capacity, and abundance in the earth's crust. Achzet and Helbig (2013) highlight other risk factors: demand growth, market balance, commodity prices, and temporary scarcity. As demand increases, these factors can lead to fluctuations in availability and pricing, resulting in an unstable market.

Other risks identified by IRENA (2023) are climate change and natural disasters. These can have a direct effect on the availability of resources. For instance, extreme weather events of environmental regulation can disrupt production and distribution This highlights the importance of strategies that enhance resilience against such events.

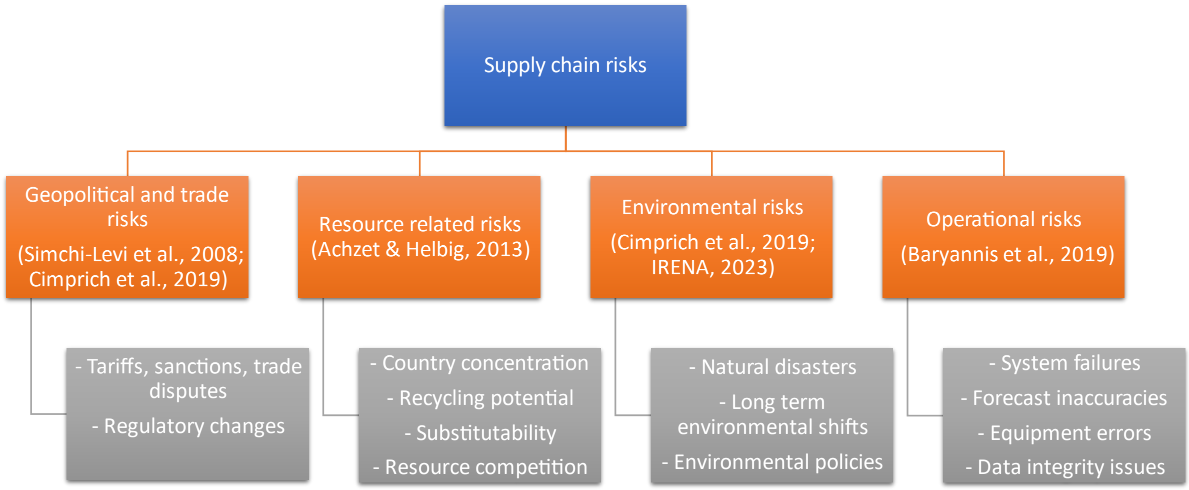

Figure 2-7: Categorization of risks based on literature.

2.6 Risk mitigation strategies

Nabi et al. (2020) argued that economic analyses and price trends influence the adoption and diffusion of renewable energy technologies. This suggests that the availability and pricing of critical raw materials, particularly those sourced from China, can significantly impact the deployment of renewable energy technologies. This highlights the importance of examining the upstream supply chain risks associated with the dependency on China for critical raw materials used for renewable energy technologies. While it is true that there are concerns about the dependency on China for components and materials, it is also essential to consider opposing arguments. Efficient policies, investments and adapting new technologies has made China a major player in the global market.

Building resilience through redundancy, flexibility, and culture. Sheffi et al (2005) propose that resilience can be cultivated by creating redundancies, increasing flexibility, and fostering a responsive corporate culture. Redundancy involves maintaining backup resources, such as extra inventory and multiple suppliers. In case of disruption, a company can switch to a different supplier in this case. However, this approach will result in increased costs. Therefore, companies will have to balance the tradeoff between cost and redundancy. Sheffi et al. (2005) argue that incorporating redundancy—such as maintaining safety stock or working with multiple suppliers—can enhance resilience by providing a buffer against disruptions. Christopher and Peck (2004) support this view, noting that resilient processes must embody agility and flexibility. They highlight the need for proactive risk mitigation strategies, including supplier diversification, risk assessment, and continuous monitoring of supply chain dynamics. Flexibility is a strategy that allows companies to quickly adapt to disruptions. This can include flexible transportation methods, adaptable procurement strategies, and supplier relationships. Sheffi et al. (2005) argue that flexibility can be integrated into decision-making and collaborative supply chain relationships. Also, a corporate culture that emphasizes transparency and collaboration must be created. This will allow companies to identify risks early and develop effective contingency plans. Tomlin (2009) evaluates various disruption management strategies, finding that contingent sourcing is preferable in high-risk environments, while supplier diversification is more effective when demand risk is significant.

Diversification is another crucial mitigation strategy. Multiple studies explored the advantages of multiple sourcing in mitigating risks. (Constantino & Pellegrino, 2010; Sillbermayr & Minner, 2014; Koyamparambath et al. (2022)). Lerwick et al. (2021) stress the importance of diversifying sources of critical raw materials to reduce dependency on any single region. Galos et al. (2021) highlighted the significance of specific countries in the raw materials supply chain. Understanding the roles of different countries in the supply chain is essential for assessing the geopolitical risks associated with dependencies. Moreover, raw material prices play a vital role in renewable energy diffusion.

The concept Of Green Supply Chain Management is gaining interest as a way to mitigate supply chain risks while promoting sustainability. Garzon et al. (2019) argue that sustainable supplier selection should extend beyond traditional criteria such as quality and price to include social, ecological, and economic factors. The author highlights that integrating environmental considerations in procurement creates a more resilient supply chain against regulatory changes and societal pressures. Lapko et al. (2018) advocate for adopting closed-loop supply chains that focus on the sustainable flow of critical materials. Koyamparambath et al. (2022) also propose recycling to mitigate supply risks. This approach supports environmental sustainability and addresses supply chain inefficiencies.

Strategic Risk Mitigation Frameworks. Several frameworks have been widely adopted to guide risk mitigation strategies in supply chains. For example, Kraljic's matrix (Kraljic, 1983) is widely used for risk assessment and supplier segmentation. It categorizes products based on profit impact and supply risk. By positioning products within this matrix, companies can tailor their strategies to minimize supply vulnerability and optimize buying power. The four proposed strategies are forming partnerships, assuring supply, exploiting power, and ensuring efficiency.

Emerging technologies and digitalization. The adoption of technology plays a significant role in enhancing resilience. Technologies such as AI, IoT and advanced robotics can improve transparency, efficiency, and responsiveness (Ivanov et al.,2018). They note that these technologies are still in the early stages of adoption but offer substantial potential for risk mitigation. However, digitalization also introduces new risks, such as cybersecurity threats. Ning et al. (2022) suggest that companies must balance the benefits of technology adoption against the vulnerabilities, ensuring a resilient and secure supply chain.

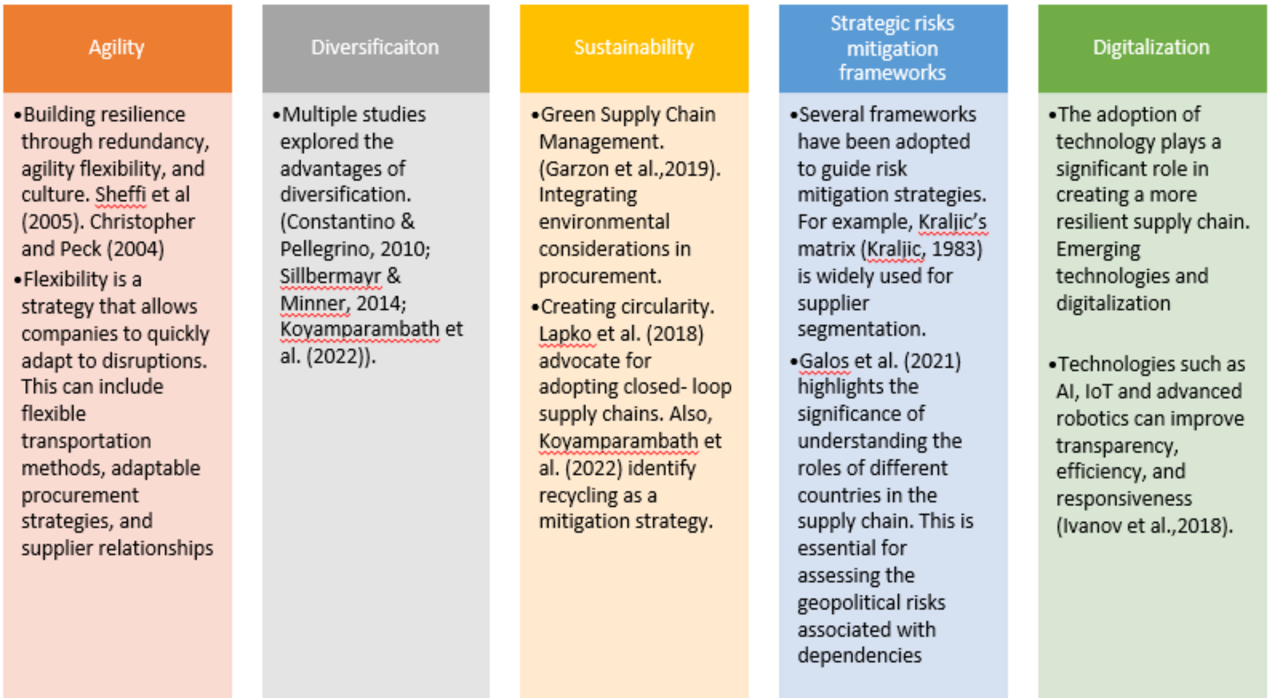

Figure 2-8: Risk mitigation strategies from literature

3. Methodology

3.1 Research Design

After examining the concepts and theoretical fundamentals of supply chain risk management, procurement, energy transition, and sustainability, this part of the thesis will conduct a study to identify the risks and mitigation strategies. The main objective of this chapter is to describe the methodology and data collection techniques in detail. The research will emphasize how businesses navigate challenges within their upstream supply chains. In the context of renewable energy technology, a notable need exists for more scholarly investigations. This chapter outlines the research design, sampling techniques, data collection and analysis, and potential study limitations. The methodology adopted for this research is designed to provide a comprehensive understanding of supply chain challenges related to the energy transition.

The methodology employed in this study is qualitative and exploratory, a choice driven by the limited research on supply chain vulnerabilities within the renewable energy sector due to the novelty of the subject. To address this gap, in-depth interviews were conducted with ten industry experts to identify and explore potential risks and mitigation strategies in the supply chain. The interviews took 33 minutes on average. Expert interviews will help to identify complex issues that are difficult to quantify because of data access limitations. This research follows a structured risk management process involving Risk identification, risk assessment, risk mitigation, and risk monitoring (ISO 31000, 2009).

3.2 Data Collection & analyses technique

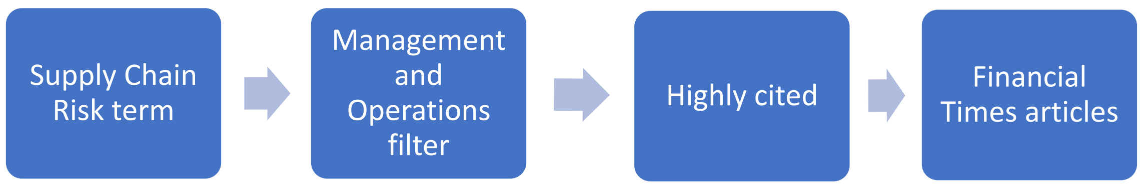

Figure 3-9: Academic article identification strategy.

Primary data: In-depth interviews with a select group of industry experts will be conducted. These interviews will be semi-structured, allowing for an in-depth exploration of supply chain dependencies, challenges, and strategies within the energy transition. The insights from these interviews will be used to construct a risk overview, providing a nuanced understanding of the various inbound logistics risks businesses face in the renewable energy sector.

Secondary data: This includes reviewing the literature on Supply Chain dependencies and Risk mitigation strategies. As the topic still lacks research, finding literature about Supply Chain dependencies and risks from non-academic resources was necessary. Web of Science was mostly used to identify suitable papers.

3.3 Data Analysis

Qualitative data from interviews undergo thematic analysis to extract key themes, challenges, and insights from the narratives of industry experts. MAXQDA24 is used for the analysis of the transcripts. MAXQDA is a web-based platform designed for collecting and analyzing qualitative and quantitative data. The platform offers features for organizing and coding textual data. Therefore, it is a valuable tool for extracting themes and patterns from interview transcripts. The coding script can be found in the Annex (Annex A).

3.4 Research Framework

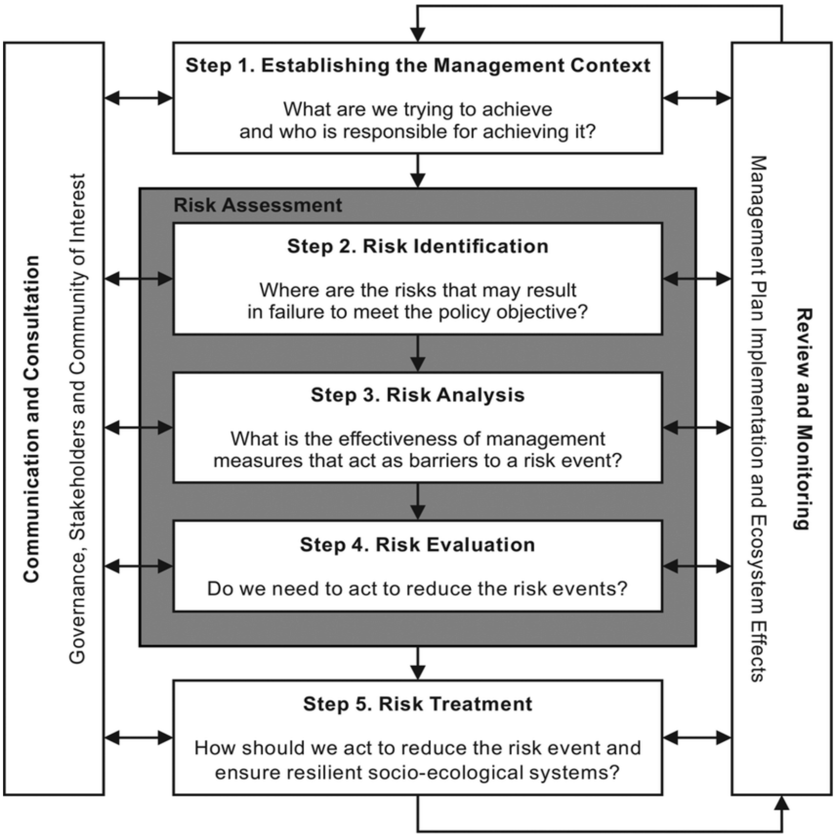

Figure 3-10: ISO 31000 framework adopted from Creed et al. (2016)

The framework outlines a structured approach to identifying, assessing, and managing risks within the renewable energy supply chain. It focuses on evaluating the potential impact and developing effective mitigation strategies. The framework serves as a guiding tool for the research process, helping to identify and categorize key themes and new findings.

The framework consists of 5 steps. In the first step, the management context is established, which is necessary to understand the issue. The second step is risk assessment, which consists of three sub steps. The first is risk identification, where we analyze potential risks and how companies identify them. Secondly, The risk analysis. What is the effectiveness of management of measures that try to prevent the risks from happening? The third step is the risk evaluation. Here, we analyze if action is required to reduce the risk events and identify the risks companies suffer. Step 5 is the risk treatment step. Here we identify what mitigation strategies companies could employ.

The goal of the thesis is to contribute to creating a deeper understanding of how to enhance supply chain resilience sustainably. It is focused explicitly on industries where companies are highly dependent on materials and components from suppliers. The energy transition is a broad industry with many different supply chains. However, most of them have in common the fact that manufacturing and raw materials are not sourced from countries within Europe. Therefore, they face similar challenges.

3.5 Participant selection

Participants were chosen based on their expertise in energy transition, supply chain management, and risk mitigation. A purposive sampling strategy ensures representation from diverse perspectives, including industry professionals, policymakers, and academics. This selection process aims to capture a broad range of insights and experiences related to the energy transition supply chain.

Experts	**Titel**	**Years of experience**	**Date of interview**	**Duration**	**Industry**
E1	Procurement Consultant	>20	15-03-2024	30:29 min	Consultancy
E2	Partner audit	>20	22-03-2024	26:02 min	Audit
E3	Procurement manager	>20	28-03-2024	40:41 min	Consultancy
E4	Procurement manager	>20	04-04-2024	48:52 min	Energy
E5	Supply Chain Consultant	>10	08-04-2024	26:10 min	Consultancy
E6	Sustainability lead	>20	11-04-2024	29:14 min	Energy
E7	Procurement manager	>20	08-05-2024	55:06 min	Energy
E8	Procurement manager	>20	22-06-2024	19:57 min	Energy
E9	Business Development manager	>20	26-06-2024	25:49 min	Energy

E10	Supply Chain manager	>20	06-08-2024	33:10 min	Energy

Figure 3-11 Overview interview participants

3.6 Research questions and theoretical grounds

The research framework that guided this study is designed to systematically address the critical components of risk identification and mitigation strategies within the supply chains of renewable energy sources. To understand the risk identification process, it is essential to discuss supply chain dependency, review critical raw material assessment methodologies, and analyze supply chain concentration in the energy transition.

It is important to understand the risk identification process of companies. Therefore, questions were asked about the procurement process, supply chain risk management practices, and the impact of regulations. (Questions 2a, 2b, 6) These questions will help assess how industry experts apply these concepts in practice. Furthermore, the energy transition must logically emphasize sustainability. Therefore, green supply chain management principles were analyzed, and questions were asked to see how green supply chain management principles are perceived and applied in the industry. For instance, questions about suppliers' sustainability, data collection, and other ESG indicators were asked.

Initially, an overview of potential risks from the literature was created. To see if these risks applied to the industry, questions were asked related to challenges in securing a sustainable and diverse supply of materials and components for renewable energy technologies, as well as what accompanying consequences it could lead to. These questions will help industry experts categorize risks and the most critical ones. In the final phase of the research, risk mitigation strategies were identified from the literature. In the final phase of the interview, questions related to supply chain resilience were asked to determine what it means in practice and what potential procurement strategies could be implemented (question 7). Also, these questions will show how active companies are working on risk mitigation.

#	Question	Reason + Link with literature
1	Please describe your position in the company, your responsibilities, and your disciplinary background.	Introduction of professional and analyze experience level.
2	How does a procurement process look like? In terms of identification of suppliers, choice of suppliers, or other collaborative processes. a. Do you have any Supply chain risk management process? b. Are there specific regulatory challenges impacting your supply chain sourcing process?	To analyze the Supply Chain process of companies. Understanding the risks associated with procurement helps companies to purchase the right materials and act before poblems occur.
3	How do you make sure a supplier produces sustainable? a. Do you collect data on ESG indicators? b. Is there a mutual exchange of data for better collaborations? c. Are there any data collection obstacles?	To test the application of green supply chain management. Garzon et al (2019) argue that sustainable supplier selection should extend beyond traditional criteria such as quality and price to include social, ecological, and economic factors
4	Can you tell me how suppliers for renewable energy technologies and components are distributed worldwide? a. What are the most crucial technologies for the energy transition? b. Are there supply chain dependencies? In which technologies? And how do you measure this?	To analyze if these companies have any dependencies in the Supply Chain.
5	What challenges do you face in securing a sustainable and diverse supply of materials and components for renewable energy technologies? a. Are there disruption risks?	To identify the risks and challenges companies are facing. In the literature some risks mentioned were Country concentration, country, depletion time, company concentration, demand growth, recycling potential, byproduct dependency, substitutability, import dependence, commodity prices, exploration degree,

	b. What kind? Natural disasters, Demand risk, quality, lead time, price volatility, dependency. c. Do you believe one of these risks has the potential to prevent the carbon neutrality goals from being achieved?	production costs of extraction, stock keeping, market balance, mine/refinery capacity, future market capacity, investment in mining, climate change vulnerability, temporary scarcity, risk of strategic use, abundance in the earth's crust. (Achzet and Helbig, 2013) Cimprich, et al; (2019) added trade risk, natural disasters, logistic restrictions, and resource competition to this list
6	Do you see a supply chain dependence as a risk? a. What consequences could it have? b. Do you think because of this dependence, there is a bigger supply chain disruption risk? What kind of risks and why?	Dependence asymmetry measures the extent to which an organization relies on a specific business partner, resulting in power imbalances. Escalating dependencies could disrupt business activities, introducing uncertainty in resource access (Ivanov and Dolgui, 2020). Therefore, it is important to identify if these companies also identify a dependency on specific suppliers.
7	How would you describe a resilient supply chain? a. Do you believe the supply chains of materials and technologies in the energy transition are resilient?	To find a definition for a resilient supply chain. This term is often mentioned in literature, but it is important to analyze what it means in practice.
8	How do you ensure resilience in your supplier base for renewable energy components/and raw materials? a. Would you change anything in your procurement strategy? b. Do you think localizing your supply chain would help? c. Do you think technology can help to mitigate supply chain risks of a dependency? What kind?	What kind of mitigation strategies do companies incorporate. For instance, digitalization (Ivanov et al, 2018), risk mitigation frameworks (Kraljic, 1983), Green Supply Chain Management (Garzon et al, 2019), Circularity (Lapko et al, 2018), Diversification Constantino & Pellegrino, 2010; Sillbermayr & Minner, 2014; Koyamparambath et al. (2022) (Understanding geopolitics (Nabi et al, 2020), and flexibility (sheffi et al, 2005)

9	What do you think about the potential of 4R practices (Reduce, Reuse, Recycle, Recover)?	To test if companies incorporate any circular economy principles. Lapko et al (2018) advocated for the adoption of closed- loop supply chains. Also, Koyamparambath et al. (2022) highlights the potential of recycling.

Figure 3-12: Overview and explanation of research questions

3.7 Conceptual framework

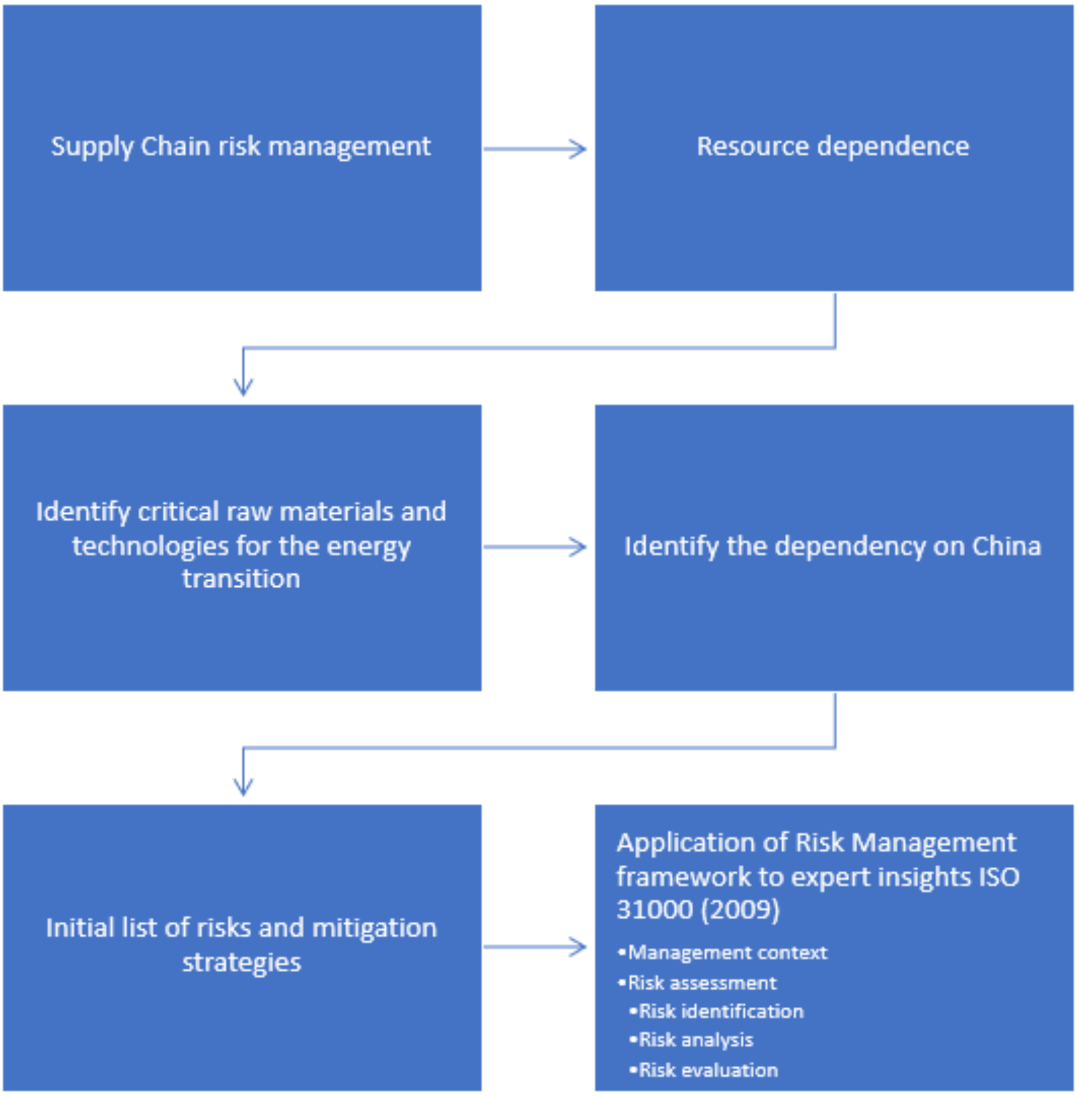

Figure 3-13: Conceptual framework

4. Findings

4.1 Procurement process

The procurement process in organizations typically involves several key steps, as evidenced by the context provided. Often, companies that provide energy solutions start with a tender phase. “The process starts when a customer or stakeholder has a demand, which triggers the tender. At this stage, you determine the scope; what does the customer need?” And what solution should we provide” (E9). This sets the foundation for the rest of the procurement steps. Once the customer’s needs are clear, you define what materials, services, or equipment will be required. This is the starting point for determining what resources are needed and from whom. Then comes the decision about who will provide the materials or services. Companies determine which vendors, contracts, or factories will be involved. Before a vendor can be selected, they go through a qualification process; one often used is SAP Ariba. This software ensures that each vendor meets the required standards and helps to mitigate risk. (E7, E8) Vendors are sent a registration link, where they answer a set of questions. In this questionnaire, information is asked about the materials or services they will provide and about their legal compliance with your code of conduct, Terms and Conditions (T&C), and non-disclosure agreement (NDA). The vendors that pass through this stage are considered eligible. After defining the scope and identifying qualified vendors, companies send out RFQs (request for quotation). These requests ask vendors to submit their proposals, including pricing and delivery options. Vendors are selected based on the best solution based on project requirements and price (E9).

Another participant added that they maintain a comprehensive list of qualified suppliers. “To ensure quality and reliability, we maintain a comprehensive list of qualified suppliers. However, with the shift towards energy transition project, we often need to identify and qualify new suppliers” (E9). The qualification is mostly done through a questionnaire and, in some cases, an inspection.

One expert (E5) highlights the importance of continuously assessing supplier performance. “Continuous assessment of supplier performance is crucial throughout this process. This involves conducting market research to evaluate suppliers based on key performance indicators (KPIs) such as quality, price, delivery time, and service reliability”. Especially for capital expenditure projects like many in the energy transition (CapEx), operational excellence is essential. CapEx typically involves significant annual investments and, therefore, has a greater emphasis on preparatory activities to ensure successful project execution.

Expert (E5) also highlights sustainability as a key focus in procurement tenders. “During the qualification stage, we establish minimum sustainability requirements that suppliers must meet. In the invitation to tender, we include sustainability award criteria to incentivize suppliers to offer more sustainable products”.

The focus for companies lies in reducing greenhouse gas emissions and promoting circularity in both the minimum requirements and award criteria. Companies should also address critical issues such as human rights (E6). Another expert continues the topic of promoting decarbonization. “When working with customers, we typically conduct a supplier segmentation. This segmentation is based on several factors, including supplier’s position in category matrices, contract renewal timeliness, and the availability of subsidies” (E1). Based on these characteristics, we build supplier pyramids and supplier engagement programs to drive decarbonization initiatives”. (E1)

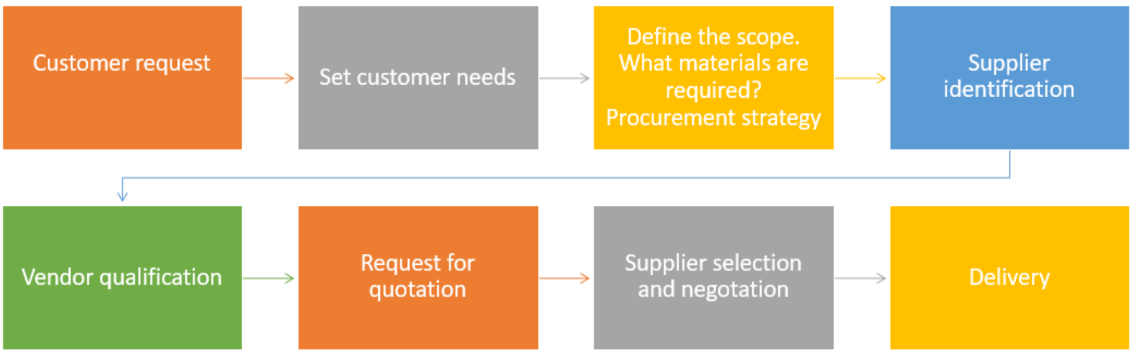

Figure 4-14: Procurement Process in the energy transition. Retrieved from expert interviews.

Another expert states that the strategy phase comes first (E4). In this phase companies determine the optimal approach for the tender. For instance, do they have to comply with European tender regulations, assess the market landscape, and conduct market consultations to decide whether to structure the tender as a single or divide it into multiple lots? Expert (E4) gave an example for a project where they wanted to connect a data center to our heat grid in Amsterdam. "The heat pump is quite large and was not readily available on the market. So, we have designated it as a separate lot. This means it will not be part of the project's overall procurement process. We carefully consider the scope of this lot and analyze the supply market to understand the available options. All these considerations shape our procurement strategy." (E4). In the literature review, we discussed the increasing importance of green procurement and sustainability in supplier selections (GSCM) (Garzon et al., 2019). This approach emphasizes including environmental considerations throughout the supply chain, such as price and quality. The interviews provided insights into how these concepts are applied in the industry. The interviews revealed that companies prioritize sustainability in their supplier identification and qualification process. Researching and evaluating potential suppliers based on indicators like quality, performance, price, and reliability. This aligns with Garzon et al. (2019), who state that social, ecological, and economic factors should be considered. What wasn't mentioned in the literature was the importance of regulations for determining your procurement/SC strategy.

4.2 Establishing the Management Context

A complex interplay of geopolitical influences, manufacturing capabilities, and resource availability shapes global distribution. In this research, it was found that the literature provides a foundation on these topics, but more real-world perspectives will deepen our understanding of how these dynamics work in practice:

An expert highlighted the importance of risk management: "Risk management is a fundamental aspect of our projects, especially given their scale. A 100-million-dollar investment is considered a small project for us. Most of our projects involve hundreds of millions or even billions of dollars" (E9). The author highlighted that risk management is integrated into every phase of project execution. "We use a proprietary risk management system with hundreds of categories the project team must review in collaboration with a risk officer" (E9). This is a process with predefined questions to identify potential risks. Once identified, the risks are documented, and the team develops corresponding mitigation strategies. If a risk cannot be fully mitigated, they classify it as a remaining risk, for which we allocate a budget that they call a contingency fund. This approach is consistent with the broader SCRM frameworks found in the literature. Halikas et al. (2014) outline a four-step approach, including risk identification, risk assessment, risk management and monitoring –

often referred to as ISO 31000. In practice and literature, a structured approach is essential for effectively managing supply chain risks.

Legislations, such as the EU's Sustainability Reporting Directive, are driving companies to delve deeper into their supply chains to understand and report on the ESG impacts of their activities, both upstream and downstream. This includes accounting for emissions from the production and use of their products and working conditions throughout the value chain.

"It is new for 2024. So, companies are working on it as we speak. And, if you look at the whole value chain, several companies need information from probably the same supplier." (E2).

Companies face significant pressure from shareholders to operate sustainably, even in regions with weaker governance. "Generally, we refer to major mining companies, such as BHP Billiton. These enterprises are often publicly traded, which means their shareholders hold them accountable for sustainable production practices. While not all companies may fully incorporate these standards, the pressure to operate sustainably is significant. Although, some companies operate in regions in Asia or South America, where governance is less stringent than in western Europe.". (E9). This indicates that sustainability is becoming a critical factor in supply chain dynamics, adding a dimension to the supplier landscape that the literature does not fully capture. As highlighted by Mitchell & Yu (2021), it is true that base metals such as aluminium, copper, nickel, tin, and zinc are publicly traded. However, materials such as cobalt and rare earths, are not traded publicly, resulting in transparency issues for sustainability assessment. Although Chinese companies are very strong regarding production capacity and costs, European companies might be using sustainability and transparency as a competitive edge.

The interview findings also provide additional context and highlight how regulations and logistical challenges make companies prefer indirect purchasing. "Direct buying from outside Europe will require you to manage these logistics, which can be very complex, as it involves additional environmental regulations and costs. This is why we sometimes prefer to purchase from intermediaries, as it simplifies the supply chain." (E8) Furthermore,

ESG (Environmental, Social, Governance.) data is becoming increasingly important for companies as they seek to understand and manage the sustainability and social impact of their operations and supply chains. "Companies have started implementing some tools, like interview forms and questionnaires. However, they are not as advanced as they would like to be. Ultimately, every company must comply with upcoming legislation, which requires addressing scope three emissions. I think they are making progress, but there are still improvements.” (E5)

4.3 Risk assessment

The risk assessment steps consist of three sublevels: risk identification, risk analysis, and risk evaluation. Each step is vital for a comprehensive risk assessment. In the risk identification phase, we explore the tools and criteria that companies use to identify potential risks. During the risk analysis phase, we investigate how companies evaluate the severity and likelihood of the risk. In the risk evaluation phase, we determine the most critical risks and assess their potential consequences.

4.3.1 Risk identification

Risk identification is critical, especially for projects with limited supplier options (bottleneck situations). Most companies identify risk in the early stages, assessing how many suppliers are available and the criticality of the components. (E1) implements third-party risk management tools and conducts end-to-end value chain analysis for companies to review their risks better. (E4) states that risk identification begins by evaluating the complexity of the supply chain. For critical materials, it is important to analyze where components are complex to source; companies identify risks by assessing bottlenecks and determining if stock reserves or multiple suppliers are necessary.

Multiple companies incorporate risk identification into their category management strategy. (E3) The risk levels of contracts are evaluated based on low, medium, or high. High-risk items require procurement specialists to identify potential risks before contract execution. After contracting, risks are also closely monitored. (E3) mentions the usage of the Kraljic Matrix. This standard tool helps companies categorize their procurement items based on risk and strategic importance. This matrix could be a helpful starting point for identifying strategic items. However, it does not provide a concrete risk indicator. Some criteria used for risk identification include assessing reliance on specific suppliers. Both (E10) and (E4) identify risks based on the number of available suppliers in a given category. In these cases, it is crucial to evaluate supplier reliability and country risks for a high supplier dependence. Also, some companies investigate the financial stability of suppliers. They are identifying the financial health of suppliers to prevent disruptions (E8). This is supported by Halikas et al.

(2004), who underscore the financial importance of risk identification. Additionally, companies investigate geopolitical conditions in supplier countries to anticipate potential risks. This aligns with the literature, which highlights the importance of understanding the broader environment in Supply Chain Risk Management (Shi et al., 2011)

For a more comprehensive risk identification process, companies should further investigate the probability of supply disruption, as mentioned by Lütkehaus et al. (2021). This includes indicators such as the concentration of mining sites in a single or only a few countries, monopolistic characteristics of companies, raw materials abundance, recyclability, and substitutability. Halikas et al. (2004) support using risk identification tools and advocate systematic risk identification as the first step in effective supply chain risk management.

4 .3.2 Risk analysis

"A resilient supply chain can withstand and adapt to disruptions, ensuring the continuity of supply". This is a key finding from the provided E5, E1, and E10 sources. Proactively identifying supply chain risks, whether in materials, transportation, or others, is crucial to developing effective mitigation strategies (E4). This involves a thorough understanding of weaker points in the supply chain. Companies must adopt robust risk analysis frameworks in the increasingly complex and interconnected global marketplace to manage their supply chains effectively. A critical component of this process involves assessing the sustainability practices of suppliers, which is essential for mitigating ESG-related risks.

Companies employ a multi-step process to analyze suppliers, including questionnaires, documentation, and on-site inspections, to assess sustainability practices and issues like child labour (E9). Other companies take it one step further, using quantitative data such as life cycle assessments (LCA) and supplier greenhouse gas emissions, utilizing tools like environmental cost indicators (E6). Such practices reflect the trend towards more comprehensive and objective supplier sustainability practices. Several strategies are employed to enhance their supply chain risk analysis, particularly concerning sustainability (E1, E6).

- Early warning systems: Implement systems that detect signs of potential disruptions before they escalate into significant issues.
- Supplier audits: Regular supplier audits ensure suppliers meet performance standards. These audits often include ESG indicators.

Sustainability tracking: Monitoring metrics related to environmental impacts, such as carbon emissions and resource usage, is essential for companies to reduce their environmental impact.

The findings provide new insights into integrating sustainability considerations into risk assessment. Although the literature acknowledges the importance of sustainability in risk management (Gong et al.,2018), our findings highlight the growing relevance of integrating factors like greenhouse gas emissions and critical raw material assessments into risk evaluations. This reflects an increasing focus on environmental impact that is still developing in the literature.

The emphasis on analyzing factors such as supplier dependencies and financial stability is consistent with the literature. Shi et al. (2011) discuss the complexities of assessing risks in uncertain environments. This highlights the need for a thorough assessment process that evaluates supplier performance and environmental impact (E9, E8). The importance of assessing supplier performance is further underscored by the findings of Swierczek (2014), who highlights the "snowball effect" of unmitigated risks. Minor issues within the supply chain can escalate into significant disruptions if not correctly managed, making continuous performance evaluation essential for risk mitigation.

Furthermore, integrating sustainability considerations, such as GHG emissions, into risk assessments is increasingly vital as companies prepare to comply with emerging regulations. The upcoming Corporate Social Responsibility Directive (CSRD) mandates reporting on scope three emissions (ISO 14064) and other sustainability data from suppliers (E6). Compliance with these regulations will require better collaboration within the industry, particularly given the differences in regulatory stringency between regions. For instance, Europe’s more stringent requirements than those of the Americas or China mean that companies must be well-informed about the specific regulations applicable to their suppliers' regions (E2).

Despite the advancements in risk analysis, companies need help in collecting and sharing sustainability data with their suppliers and across industries. These challenges include data standardization, supplier readiness, transparency, and technological limitations. The lack of uniform standards for sustainability, as highlighted by (E8), complicates the comparison and aggregation of data across different suppliers and industries and makes it difficult to conduct accurate risk analyses. Supplier readiness and transparency further complicate the effectiveness of sustainability initiatives. Therefore, ESG considerations should be integrated into procurement practices, covering scopes 1-3 emissions and social indicators (E8). This will ensure that sustainability is a crucial criterion rather than a compliance requirement.

Another participant (E7) notes that sustainability certifications are becoming an essential tool in supply chain risk analysis. They use EcoVadis certifications to evaluate the sustainability of its suppliers. This certification focuses on optimizing the supply chain and reducing environmental risk. Certification enhances transparency and provides a standardized method for assessing supplier sustainability. (E4) collects emission data through the Carbon Disclosure Project (CDP), reflecting a solid commitment to transparency of their operations. The new Corporate Sustainability Reporting Directive (CSRD) drives companies to scrutinize their entire value chains to understand and disclose their ESG impacts. EY (SC) highlights the increasing regulatory demands around sustainability reporting, compelling companies to better understand their upstream and downstream supply chains (E5, n.d.). This includes assessing their suppliers' environmental and social impacts, which is becoming an essential part of regulatory compliance and corporate responsibility. In addition to these practices, E1 (n.d.) suggests various methods for assessing supplier sustainability, including ratings and certifications, CDP submissions, policies, and product-level digital passports that provide complete material disclosures. These methods offer a comprehensive approach to understanding and managing the sustainability risks associated with suppliers.

4.3.3 Risk evaluation

The literature discusses the risks associated with China’s control over critical raw materials, such as rare earths, lithium, and Cobalt (Hulatt, 2019; IEA,2021). The findings further elaborate on how Europe is responding to this. The EU tries to reduce dependence on Chinese raw materials through initiatives like the Critical Raw Material Act. “Almost 80% of all critical raw materials are sourced from China. This creates a significant dependency. The European Union initiated the Critical Raw Materials Act (CRM) to address this issue to reduce reliance on sources. Given the current geopolitical environment, this initiative has become even more vital” (E1)

As demand for clean energy technologies rises, ensuring a stable supply to meet this demand becomes increasingly important. For renewable energy producers, this imbalance can impact business cases and slow investments in new projects (E6). If demand outpaces supply, this may increase prices and make it more difficult to make profits, potentially slowing down the energy transition (E1). This challenge will require careful planning and coordination between regulators and companies in the energy transition.

Availability of sustainable materials. The sourcing of materials presents significant challenges for companies trying to improve their environmental impact. Cobalt's ethical and environmental drawbacks, for instance, have received attention in recent years. Similarly, the challenges of obtaining low-emission steel (green steel) have been highlighted in the interviews. This material is vital for the construction of sustainable infrastructure and the development of green technologies. (E2, E9, E6). Companies might continue using less sustainable alternatives without a reliable supply of sustainable materials. Besides, the scarcity of sustainable materials can drive up costs, making investments in green technologies more difficult to justify to stakeholders and shareholders.

A significant challenge in evaluating supply chain risks is suppliers' varying readiness levels, particularly focusing on sharing detailed information about ESG and CSR metrics. Smaller companies especially lack the necessary infrastructure or expertise to provide comprehensive data. This information gap presents a critical risk for companies striving to manage their supply chain sustainably and transparently. (E8, E4). One participant described that while larger suppliers were becoming more advanced in their data-sharing capabilities, smaller companies were still struggling with basic ESG reporting requirements (E8). This imbalance creates a fragmented data landscape and makes it more complicated to ensure that sustainability initiatives are implemented effectively throughout the supply chain. Also, suppliers find it difficult to keep up with the rapidly changing regulatory environment, potentially leading to inaccuracies in the provided data.

Another critical issue is the lack of standardization in data collection methods. One participant (E6) describes that finding the right tool that all members can use remains an issue. Also (E2) acknowledges this. The participant states that there is a lack of mature data management systems and platforms to facilitate efficient data sharing. Consequently, many companies still rely on manual requests for CO_2 emission data rather than retrieving it from a centralized platform. Initiatives like CDP aim to resolve this by standardizing data collection through uniform templates. Although CDP provides a useful framework, it does not fully comprehend the unique characteristics of different industries. “Many suppliers provide services across multiple sectors; therefore, different divisions of the same company may report conflicting information about the industry they operate in. (For example, one division may report it operates in sector A while another claims to operate in sector B. Such inconsistencies make the data less reliable and harder to use for sustainability assessments" (E6).

The industry has a high demand for sustainable production data but only a limited number of high-quality suppliers. This can lead to gaps as suppliers with significant market power may be less willing to be transparent in their data (E5). The most optimal would be an open-booking costing structure, where detailed cost breakdowns are shared with the customer. With such a structure, it becomes easier for companies to understand their suppliers' cost structure and the factors driving it. However, one participant (E2) mentions that suppliers might be reluctant to share such sensitive information as they are concerned about losing competitive advantage.

The evaluation of risks related to supply chain disruptions is complex. If a primary supplier cannot meet demand, companies might have few alternatives, leading to delays and increased costs, or must accept a lower-quality product (E5). For the international supply chain, these risks can be worsened by geopolitical events or disruptions in transportation routes. For example, the Suez Canal blockage shows how a single event could significantly affect global supply chains. (E4). One area of concern is the lithium supply chain, which is critical to producing batteries in electric vehicles (EVs) and other renewable energy technologies. Participant (E9) gave an example of Volkswagen, which faced challenges securing the necessary equipment for its European battery plants. He noted that placing battery production facilities is vital to managing supply chain risks. If these facilities are located too far from the manufacturing hubs, this could lead to delays and increased costs. Similarly, the availability of specialized equipment and parts suppliers can disrupt the supply chain, requiring careful management and coordination.

(E7) notes that current infrastructure and technological limitations make reaching the net zero emission goal challenging as there is no transportation alternative with zero emissions. He highlights the lack of funding for developing new technologies that could accelerate the energy transition. Without higher investments, it will be challenging to overcome technical barriers specifically because of the high costs associated with implementing more sustainable technologies. Especially when existing infrastructure still has a valuable life, companies will not be likely to invest in the more sustainable options E4, E6). The high costs associated with implementing sustainable solutions represent a barrier to broad adoption. Also, this is a significant issue for the wind sector. The turbines are increasing in size, and therefore, the transportation vessels must also get bigger and become quickly outdated. Consequently, this will require continuous investments (E6). Also, replacing coal-fired power plants with renewable energy facilities requires a significant investment, ongoing maintenance, and extra operational costs. These costs are often higher than costs associated with traditional energy sources.

Balancing between sustainability and technical requirements is another challenge. Engineers often design systems that meet strict technical specifications while minimizing environmental impact. For many industrial products, minimizing the use of materials such as copper, aluminum, and plastics is a big challenge despite their environmental drawbacks (E7). The need for high-performing materials often outweighs environmental considerations, leading to the continued use of materials with significant carbon footprints. Another example the participant gave was using concrete and steel, which remain popular due to their strength and durability, even though they are associated with high carbon emissions. These challenges highlight the need for innovative solutions that meet technical and sustainability requirements. Developing such tools will require significant investments in research and development.

Issue	Risks	Consequences
Supply Chain Disruption	Disruption risk due to geopolitical events, transportation challenges, or supplier failures ((E7, E2, E1)	Delays, increased costs, and lower quality of products. (E6). Disruptions in key transportation routes, such as the Suez Canal, can impact lead times and availability of materials (E5, E1)
Demand and availability of raw materials	Limited availability of materials used for sustainable technologies such as cobalt, green steel, and lithium (EY, E9)	Higher costs and reliance on less sustainable alternative, potentially slowing down the energy transition (E1, E6)
Data management and transparency	Inconsistent ESG/CSR data, and lack of standardized data collecti on method (E6, E2)	Difficulties in assessing and managing sustainable initiatives in the supply chain (E2, E6)
Investments	Significant investments required for replacing existing infrastructure and more maintenance costs (E6, E7)	Financial barriers for wide adoption of sustainable technologies. (E7, E6)
Research and Development	Challenge is to meet the technical requirements while enhancing sustainability.	Continued use of high-carbon footprint materials.
Supply chain Dependency	Dependence on a limited supply sources for critical materials and components (E5)	A lack of diversification in the supplier base makes supply chains more fragile and could lead to supply chain disruption, delays, higher costs, and lower- quality alternatives. (E1, E8)

Figure 4-15: Challenges and risks identified by expert interviews.

4.4 Risk treatment

The literature mentions that dependence on external partners can introduce vulnerabilities and uncertainties. Organizations should, therefore, structure their exchange relationships (Cyert & March, 1963). The level of dependence is influenced by the importance of the resource and the availability of alternatives. As Ivanov and Dolgui (2020) note, escalating dependencies can disrupt business activities by introducing uncertainty in resource access. Especially in the energy transition, companies are becoming increasingly dependent on critical raw materials and technologies, making risk management a critical aspect. This chapter explores potential risk mitigation strategies, integrating theoretical frameworks and empirical findings. The focus is on how companies can enhance supply chain resilience. One participant describes it as follows: A resilient supply chain can withstand and adapt to disruptions, ensuring the continuity of supply (E10). Investing in the right technologies and exploring alternative options can help mitigate risks and improve a supply chain's ability to withstand crises (E5). Building resilience into a supply is an ongoing process, especially in complex, long lead-time industries like wind energy (E1). In such industries, continuous improvement and proactiveness are essential to ensure resilience.

Diversification is a critical strategy for mitigating supply chain risks. Studies emphasize the benefits of multiple sourcing to reduce the impact of disruptions (Silbermayr & Minner, 2014; Koyamparambath et al., 2022). Lewicki et al. (2021) stress diversifying sources to minimize dependency on a single supplier or region. Participants highlight the need to diversify suppliers, especially for critical components. Nevertheless, sometimes, it can be not easy to diversify your supplier base. One participant says, "The demand for specific materials or components is exceptionally high, but the supply does not match. While there are many suppliers, they do not offer the same quality. So, everybody seeks for the top-tier suppliers." (E5). Localizing production and sourcing closer to the end market can help mitigate risks associated with global transportation and geopolitical tensions (Hou, 2019). It reduces complexity, and companies get more control over their production processes. Research findings support that maintaining production within Europe reduces the risks associated with a long and complex supply chain (E7; E4). However, legislation and supportive policies are vital to creating a stable investment environment in more local production.

Balancing the energy mix is also an important aspect. Leveraging a range of clean energy technologies is essential for balancing the energy mix and minimizing the dependency on one supplier. For instance, renewable energy inputs are required to produce green and blue hydrogen. In this case, including different renewable energy sources will decrease the probability of supply disruptions (E9, E4). E4 states that diversifying the energy mix contributes to optimizing overall energy usage. For example, in Nordic countries, such as the Netherlands and the UK, wind power is abundant. Regions like the Middle East are more suitable for solar energy. It is important to consider these geographic factors (E9). This approach aligns with the call for a diverse mix of renewable energy sources to ensure a balance between supply and demand (IEA, 2021)

Data transparency and collaboration are essential for effective supply chain risk management and are often neglected in the literature. Technology in supply chain management can enhance visibility and traceability across the supply chain (E1). Regular supplier audits and sustainability tracking are critical for continuous monitoring and proactive risk management (E4, E1). Therefore, a mutual data exchange is valuable in making suppliers more willing to provide the necessary information. A lack of a standardized data collection method currently hinders obtaining accurate product data. Besides, not all suppliers are at the same level of maturity in providing the required data (E10). An initiative like The Carbon Disclosure Project (CDP) addresses this challenge by collecting sustainability data from all suppliers using a single, unified template (E6). Although, this does not answer the call for detailed digital product passports (E1, E6).

According to (E1, E6), product-level data is crucial for in-depth sustainability assessments. This type of information could be enabled with blockchain technology. Blockchain technology has the potential to enhance supply chain visibility by providing a secure and decentralized platform where product specifications, origins of materials, and transactions can be tracked. Nevertheless, one participant states that blockchain technology is particularly relevant for faster supply chains, such as Fast-Moving Consumer Goods (E1. Other technologies that are being explored are AI, building information modelling (BIM), blockchain, and predictive maintenance better to anticipate potential supply chain risks (E5).

Industry collaborations: (E10) organizes conferences where suppliers share technical learning to improve performance. “We typically bring suppliers together in joint conferences to compare the performance of various assets and logistical facilities to improve overall performance”. According to this participant, it is important to set clear expectations and requirements for data provision from suppliers (E10).

Another strategy identified is to reduce dependency on critical raw materials by increasing circularity (E9). Lapko et al. (2018) highlight the need for closed-loop supply chains for critical materials in the renewable energy sector. One participant (E6) also highlights the potential to reuse and refurbish components like batteries to extend product lifespans. (E7) mentions that materials like iron and cables can be quickly melted down and reused, demonstrating the circularity potential. (E1) also notes the high recycling potential for solar panels and suggests that recyclability can help to decrease dependency on critical raw materials. Although recycling and reusing also bring new challenges. Specifically, rapid technological advancements make reusing components challenging (E6). A participant notes that there are many start-ups already focusing on recycling. “But to get a real business going, they will need a constant supply of material input and to sell your recycled materials for a good price. I think that is very challenging”. (E6). Other participants also talked about the feasibility of recycling and the cost-effectiveness of materials like cobalt. (E10) calls for more government incentives to drive the adoption of recycling and other sustainability practices. (E9) takes it further and calls for a carbon penalty to stimulate sustainability practices.

Figure 4-16: Overview mitigation strategies. Extracted from interviews.

5. Conclusion

This study follows a structured risk management framework (ISO 31000, 2009). It consists of five steps: first, establishing the management context; then, the risk assessment phase consists of risk identification, risk analysis, and risk evaluation. Finally, the risk treatments are proposed in the final phase. Utilizing this framework, this study effectively addresses its research questions.

RQ1: To what extent is there a dependency on critical materials and components?

As companies try to shift towards renewable energy sources, the importance of securing critical raw materials and advanced technological solutions grows. Almost 80% of all critical raw materials are sourced from China. In response to this dependency, The European Union initiated the Critical Raw Materials Act (CRM). The increasing dependence on external parties for resources and components, particularly in industries undergoing rapid transitions such as the energy sector, underscores the vulnerabilities and uncertainties companies are facing in maintaining a stable supply chain. Ivanov and Dolgui (2020) emphasize that businesses may face disruptions as dependencies escalate, especially in an industry like the energy transition, where many critical raw materials are required. The findings in this study highlight several strategies for managing these risks while enhancing supply chain resilience. A resilient supply chain can adapt and withstand disruptions, ensuring the continuity of supply (E10). This concept forms the foundation for the recommendations in this chapter.

RQ2: What are the immediate and long-term risks and vulnerabilities associated with procuring critical inputs for the renewable energy sector, such as rare earth elements, nickel, copper, lithium, and cobalt?

Proactively identifying supply chain risks, whether in materials, transportation, or others, is crucial to developing effective mitigation strategies (E4). This involves a thorough understanding of weaker points in the supply chain. Companies must adopt robust risk analysis frameworks in the increasingly complex and interconnected global marketplace to manage their supply chains effectively. A critical component of this process involves assessing the sustainability practices of suppliers, which is essential for mitigating ESG-related risks. Companies employ a multi-step process to analyze suppliers, including questionnaires, documentation, and on-site inspections, to assess sustainability practices and issues like child labour (E9). Other companies take it one step further, using quantitative data such as life cycle assessments (LCA) and supplier greenhouse gas emissions, utilizing tools like environmental cost indicators (E6).

The EU's sustainability reporting directive drives companies to gather and assess ESG data from suppliers. Companies must report on both upstream and downstream ESG impact, adding a layer of complexity to supply chain management. They do this through various processes, such as supplier questionnaires, on-site inspections, and data collection on carbon footprint and recycled content. However, there is a lack of a common data collection framework. This study showed that companies do three things to try to prevent disruptions. They incorporate early warning systems that can detect signs of potential disruptions before they escalate. Second, they perform regular supplier audits. These are crucial to ensure that suppliers meet performance standards. Third, sustainability tracking. Monitor metrics related to environmental impact. One participant (E6) called for more product-specific data (digital product passports) for better in-depth sustainability assessments. This could be further specified in future studies. Also, other technologies, such as the role of blockchain technology, IoT and predictive maintenance, could be further explored.

Some other risk identification indicators are Country risk, where geopolitical conditions are measured, financial stability, and the financial health of suppliers. Despite the advancements in risk analysis, companies face challenges in collecting and sharing sustainability data. These challenges include data standardization, supplier readiness, Transparency, and technological limitations. The lack of uniform standards for sustainability complicates the comparison and aggregation of data across different suppliers and industries and makes it difficult to conduct accurate risk analyses. The findings provide new insights into integrating sustainability considerations into risk assessment. Our findings highlight the growing relevance of integrating factors like greenhouse gas emissions and critical raw materials assessments into risk evaluation.

This research found a few risks related to a high dependency on a specific region or supplier. One risk is the risk of availability. The interviews underscored the limited availability of materials used for sustainable technologies, such as Cobalt, green steel, and lithium (EY, E9). This could result in higher costs and reliance on less sustainable alternatives. According to the research, a lack of diversification in the supplier base makes supply chains more fragile. It could lead to supply chain disruption, delays, higher costs, and lower-quality alternatives, such as the availability of sustainable materials.

The sourcing of materials presents significant challenges for companies trying to improve their environmental impact. Cobalt's ethical and environmental drawbacks, for instance, have received attention in recent years. Similarly, the challenges of obtaining low-emission steel (green steel) have been highlighted in the interviews. Another risk is supply chain disruptions in key transportation routes or geopolitical events, such as the Suez Canal, which can impact lead times and materials availability issues (E5, E1).

Data management and Transparency. There is a lack of one standardized data collection method. This makes it difficult to assess and manage sustainable initiatives in the supply chain—a lack of standardized methods for collecting and sharing data currently hinders supply chain transparency. Initiatives like the Carbon Disclosure Project (CDP), which collects sustainability data using a unified template, represent a step in the right direction. Our experts suggest that higher investments are required to replace existing infrastructure and maintenance costs. Research and development. Not all technologies are advanced enough to meet the high technical requirements while enhancing sustainability.

RQ3: What alternative sourcing strategies and supply chain configurations can be developed to mitigate the identified risks and ensure a sustainable supply of essential inputs for renewable energy technologies?

To handle the risks mentioned above, companies employ different risk mitigation strategies. Diversification of supply sources and strategies. Many studies already emphasized the importance of multiple sourcing to reduce the impact of disruption. (Silbermayr & Minner, 2014; Koyamparambath et al., 2022). Lewicki et al. (2021). The authors notably advocate for diversifying suppliers for critical components to provide more flexibility in responding to shifts in global markets. While diversification is ideal, it cannot be easy to implement, especially for materials with high demand and limited qualified suppliers. Besides selecting multiple suppliers, diversification also means including a different technology in the energy mix strategy. Participants highlight the need to diversify the energy mix by incorporating renewable sources such as wind, solar, and hydrogen. This approach reduces the risk of supply disruptions and optimizes overall energy usage. However, diversification of suppliers is difficult to implement, especially for high demand materials with limited supplier options.

In addition to diversification, localization has emerged as a key mitigation strategy for long and complex global supply chains. Localizing production gives companies more control over their production processes, reducing the dependency on international logistics and geopolitical tensions (Hou, 2019). Interview participants confirmed this belief (E7 and E6). However, they noted that localization also comes with its challenges. Supportive policies and legislation are vital to create a stable investment environment for local production. For instance, government incentives, infrastructure investments, and policies encouraging local innovation might help companies with the challenges of nearshoring.

Also, the findings showed that industry collaborations are essential in enhancing supply chain resilience. One participant (E10) organizes conferences where suppliers gather to share technical learnings. Also, technology can contribute to better industry collaborations. Supply Chain visibility and Transparency are essential for effective risk management. Technologies like blockchain, artificial intelligence (AI), predictive analytics, and building information modelling (BIM) have been identified as critical tools, enabling companies to anticipate better and manage risks—AI and predictive maintenance offer promising solutions for anticipating supply chain risks before they occur. By analyzing large datasets, these technologies can provide early warning signals for disruptions. BIM allows companies to visualize the entire supply chain and identify potential bottlenecks. Blockchain has the potential to provide a secure and decentralized platform where product specifications can be easily tracked. This could be important for obtaining product-level data for in-depth sustainability assessments.

One participant (E1) noted that blockchain is more relevant for faster-moving industries, such as Fast-Moving Consumer Goods. However, we believe blockchain could address some of the challenges surrounding data transparency in the supply chain, such as the lack of standardized data collection methods and varying maturity levels. Therefore, the potential of this technology in slower supply chains, such as in the energy transition, must be further discovered.

Finally, circularity presents a long-term strategy for reducing dependencies on raw materials. By reusing and refurbishing components like batteries and recycling materials like iron, companies can extend product lifespans and decrease the demand for new material inputs. The opinions about circularity are divided amongst the interview participants. They all agree that there is a massive potential for becoming less dependent on external suppliers. However, reusing is more challenging because of the rapidly advancing technologies. Also, it is difficult for recycling companies to get a real business going. Therefore, they will need a constant supply of material input and be able to sell the recycled materials for a reasonable price. Despite these challenges, the potential for circularity remains strong but will need the support of government incentives. One participant (E10) called for a carbon penalty to stimulate the adoption of circularity practices.

To navigate the complexities of global supply chains, building resilience through diversification, localization, technology adoption, and collaboration will become even more essential. The energy transition poses significant risks and opportunities for supply chains, requiring companies to manage their material inputs. Future research should focus on refining the circular supply chain and enhancing data transparency through digital solutions. Creating a resilient supply chain is not a one-time effort but an ongoing process that needs continuous improvements. By integrating the strategies mentioned in this research, companies could better withstand disruptions and ensure long-term sustainability.

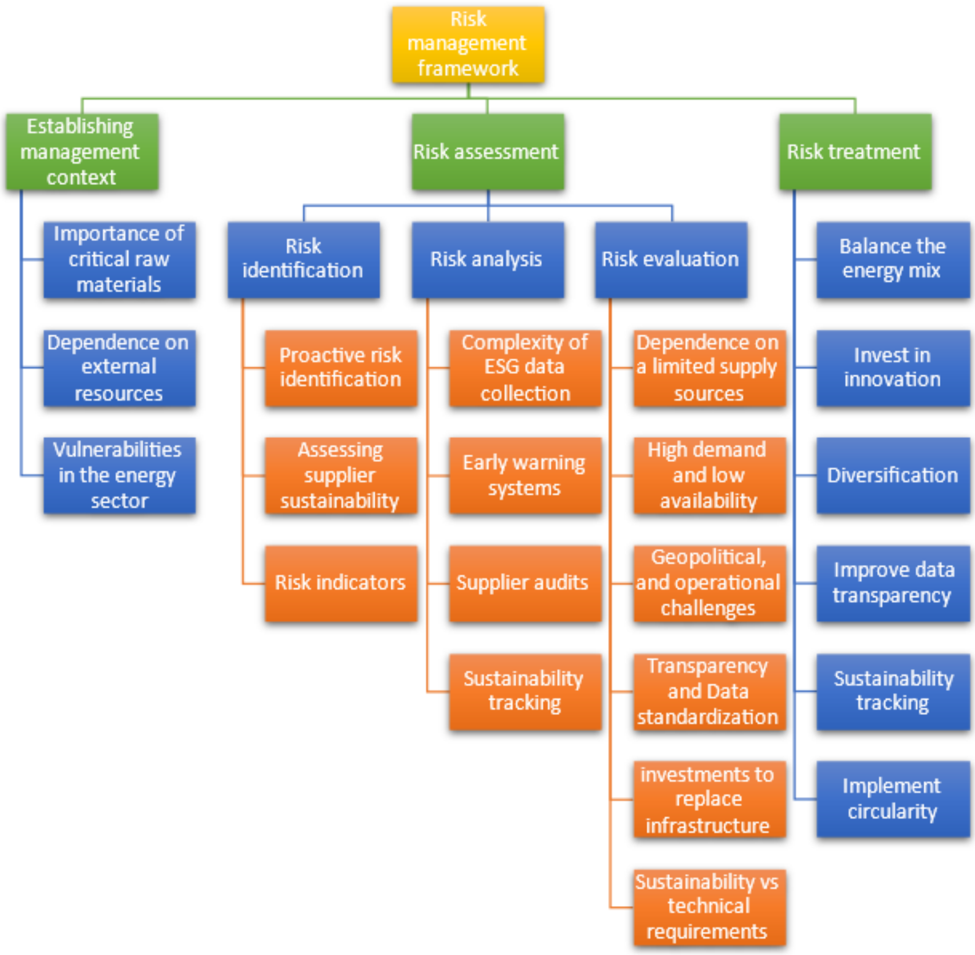

Figure 5-17: Overview research findings

Limitations

The specific themes related to risk management and the interview focus on professionals in procurement, may have led to a narrow research scope. Excluding other relevant factors influencing global supply chains. This may result in an incomplete understanding of the complexities involved in supply chain resilience and sustainability. Furthermore, this study has a geographical focus. The interviews were conducted with experts working in the Netherlands. The findings may not be applicable globally due to varying regulations, and economic contexts. This may restrict the applicability of the recommendations. The main purpose of this study was to identify the supply chain risks stemming from supply chain with a high dependency level from raw material inputs and suggest potential mitigation strategies. The findings do not rely on qualitative data, which may lack quantitative support needed for certain claims or generalizations. Further research could include longitudinal studies that track the effectiveness of risk management strategies. The potential of circularity and technologies like IoT, predictive maintenance, and BIM could be further explored. For instance, how can emerging technologies be integrated into supply chain risk management, for instance.

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Annex

Annex A: Coding scheme.

Code:	Explanation
Supply Chain Resilience	To understand the meaning and characteristics of a resilient supply chain
Procurement process	To identify how the process looks like and if companies implement Supply Chain Risk Management tools
Legislations	To identify the legislations that are moving supply chains
Supplier distribution	To analyse to what extent companies are dependening on suppliers/ specific regions
Challenges	To analyse the challenges companies are facing in their supply chain
Consequences	To identify the potential consequences of unmitigated challenges
Energy transition technologies	To identify the most critical technologies for the energy transition
Data	To identify how and what kind of data companies collect on suppliers
Technology	To analyse what role technology could play in mitigating supply chain risks
4Rs	To analyse what role 4R's can play in mitigating supply chain risks. (reduce, reuse, recycle, and recover.