Navigating Rare Earth Supply Shocks: International Business Strategies of GE Healthcare and Siemens Healthineers

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Bachelor of Arts in International Business

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Fall Semester 2025

Abstract

Rare earth elements (REEs), are essential inputs for magnetic resonance imaging (MRI) and computed tomography (CT) technologies. Their global supply, however, is highly concentrated in China, which controls most refining and a significant portion of upstream processing. This concentration exposes the medical imaging sector to recurring geopolitical shocks, as demonstrated by China's 2010–2011 export quotas and the 2024–2025 export licensing controls. The purpose of this qualitative, comparative multiple-case study is to examine how GE Healthcare and Siemens Healthineers respond to these REE disruptions and to explain why their resilience strategies diverge. The study draws exclusively on secondary data, including corporate reports, scientific literature, policy documents, and industry analyses, analysed through deductive coding and cross-case comparison.

The analysis shows that although both firms face the same REE shock, they respond in markedly different ways due to differences in capabilities, supply chain structures, and institutional environments. The findings show that although both firms depend on the same VRIN inputs, Siemens Healthineers adopts a proactive, circularity-oriented, and institutionally aligned strategy, while GE Healthcare follows a more reactive, domestically anchored approach shaped by U.S. security-driven policies. By integrating the Resource-Based View, Dynamic Capabilities, the OLI paradigm, and Institutional Theory, the study develops a multi-level explanation of resilience differences. Practical implications highlight the managerial importance of supply diversification, lifecycle circularity, institutional alignment, and advanced risk-sensing capabilities for firms operating in critical-material-dependent industries. The study also offers policy-relevant insights regarding the role of national regulatory frameworks in shaping corporate adaptation and outlines several areas for future research.

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1. INTRODUCTION

Rare earth elements (REEs) underpin the performance of some of the most essential medical technologies in the world. High-field MRI magnets rely on neodymium-iron-boron alloys doped with dysprosium for thermal stability, while gadolinium compounds remain central to diagnostic imaging. Despite their widespread application, the supply of these elements is structurally fragile: China controls approximately 60% of global mining and up to 90% of refining capacity, giving it unprecedented leverage over downstream industries. This concentration has repeatedly enabled supply disruptions, including China's 2010–2011 export quotas and the 2024–2025 export licensing regime, have repeatedly disrupted global access to REEs, causing price volatility, production delays, and uncertainty for multinational firms. These shocks expose a critical vulnerability in the medical imaging sector: the technologies that sustain global healthcare systems depend on materials sourced from a politically concentrated and strategically contested supply chain.

Existing literature has analysed various dimensions of this challenge. Scholars have detailed China's long-term industrial strategy, the persistent market volatility arising from refining concentration, and the environmental and regulatory asymmetries that cement China's dominance (Guo & Guo, 2024; Schmid, 2019). Research on supply chain risk further shows that REE disruptions can propagate across multiple tiers of global value chains, producing systemic vulnerabilities with significant operational consequences (Fan & Stevenson, 2018; Nakano & Lau, 2019). In the medical imaging sector, studies document the technological dependence of MRI and CT systems on high-purity REEs and the regulatory constraints that limit rapid material substitution (Hamed et al., 2024; Leppälä et al., 2023). Governments and industries have explored several mitigation strategies—including diversification, recycling, and substitution—but these initiatives remain fragmented, costly, and insufficient to fully offset geopolitical uncertainty.

Despite these valuable contributions, important deficiencies remain. Most existing research addresses REE vulnerabilities either from a macro-level geopolitical perspective or from a technological/material-science standpoint, leaving a gap in understanding how multinational firms in the healthcare sector strategically interpret and respond to these disruptions. Few studies compare organisational responses across institutional contexts, even though the U.S. and EU have adopted markedly different policy frameworks around critical minerals, sustainability, and industrial resilience. Moreover, although scholars recognise the strategic importance of REEs, limited work integrates international business theories—such as the Resource-Based View, Dynamic Capabilities, the OLI paradigm, and Institutional Theory—to explain why firms facing identical external shocks adopt divergent strategies. Therefore, the theoretical lenses used in this study directly address this gap by providing a multi-layered framework capable of linking resource vulnerability, organisational adaptation, and institutional differences.

Understanding how firms respond to REE disruptions carries significant implications for multiple audiences. For scholars, the study advances theoretical integration across IB frameworks and contributes to emerging debates at the intersection of geopolitics, resource dependency, and global value chains. For practitioners and medical technology firms, the findings illuminate how diversification, circularity, R&D investment, and institutional alignment can reduce vulnerability to increasingly frequent supply shocks. For policymakers in the U.S. and EU, the study highlights how regulatory environments shape corporate resilience and how industrial policy can either constrain or enable strategic adaptation. For the healthcare sector more broadly, securing stable access to REEs is critical not only for operational continuity but also for public health outcomes and long-term technological innovation. Finally, the study contributes by showing why two firms exposed to the same

REE shocks achieve different levels of resilience, a point developed further in the Discussion and Conclusion.

Therefore, the purpose of this qualitative, comparative multiple-case study is to examine how GE Healthcare and Siemens Healthineers respond to the strategic risks created by China's dominance in rare earth markets, and to explain why their resilience strategies differ. Guided by a theory-informed framework and using secondary data triangulation, the study explores how resource vulnerability, dynamic capabilities, structural supply chain decisions, and institutional pressures interact to shape organisational adaptation under conditions of geopolitical uncertainty.

2. LITERATURE REVIEW

2.1 Introduction

There are 17 heavy elements that make up rare earth elements (REEs), and their use ranges between different sectors, including renewable energy, defense systems, high tech, and healthcare machinery. Magnets, alloys, and phosphors can be found within advanced devices and infrastructures, the production of which is facilitated by the singular properties of these elements (Guo & Guo, 2024; Schmid, 2019). REEs constitute a strategic asset in both the economy and global geopolitics, as a consequence of their rarity in usable form and concentration of refining in a few regions. These supply slowdowns created production delays, rising costs and reduced competitiveness for international companies (Fan & Stevenson, 2018). This means that REE disruptions do not affect firms only through cost increases, but generate wider competitive, operational, and technological vulnerabilities that propagate across entire value chains. Next, the market structure, geopolitical and supply chain risks, the importance of REEs, how companies and governments work to mitigate the problems and theoretical perspectives that explain them will be examined.

2.2 The Rare Earth Elements Market

REEs represent A small part of the world commodity markets; the Earth's crust is rich in them. However, the deposits that can be used are found in geographical areas that are difficult to refine, making the structure of the market very challenging. The demand for materials extends to diverse sectors, such as high-tech, renewable energy, or medical devices, but their availability is limited (Guo & Guo, 2024). The market is dominated by China, with 60% control over mines and 85-90% control over refining processes (Schmid, 2019). This concentration has allowed China to create volatility and influence global prices. Between

2010 and 2011, China's restrictions on exports caused prices to rise and companies to lose interest, demonstrating how much companies are influenced by geopolitical decisions (Mancheri, 2015).

Latest studies confirm that these markets have remained subject to shock and ineffectiveness (Are rare earth stocks efficient?, 2025). China's dominance is supported by more flexible environmental regulations compared to the U.S. and the E.U. (Hamed, Turan, and Elsawah, 2024). The strategic dependencies that multinational corporations aim to reduce are based on this concentration and volatility. This means that firms face a structurally asymmetric market where supply insecurity is embedded in the system, not merely episodic. Overall, REEs are both a commodity and a fundamental resource, exploited politically yet economically vital.

2.3 Geopolitics and Supply Chain Risks

Following global pandemics, economic disputes, and geopolitical wars, global supply chains most frequently experience structural blockades (Fan & Stevenson, 2018). However, these blocks differ from normal operational risks, as they spread globally, creating "chain effects", putting entire supply networks at risk (Nakano & Lau, 2019; Herold & Marzantowicz, 2023). Resilience has become a proactive adaptation, that is, the adaptation of modalities such as supplier differentiation, digital monitoring, and buffer inventories (Fan & Stevenson, 2018; Johnson & Haug, 2021). While efficient, they are expensive; redundancy increases expenses while diversification decreases economies of scale. Resilience must have a perfect balance between efficiency and robustness, according to scholars (Hosseini Shekarabi, Kiani Mavi, and Romero Macau, 2025). There must be greater emphasis in industries where REEs are used, given that political risks and the low supply of rare elements are uncontrollable.

Since the 1990s, China has decided to strengthen itself, creating a monopoly on the entire REE market (Mancheri, 2015; Guo & Guo, 2024). In 2010, China imposed new export laws, demonstrating how such decisions can be used as a geopolitical tool, but these measures were opposed by the WTO (Wang, 2018). In April 2025, China's Ministry of Commerce introduced Announcement No. 18, in which new export controls were established. To export some rare earth elements (samarium, gadolinium, terbium, dysprosium, lutetium, scandium, and yttrium), there is a need for specific licenses. Vulnerability in strategic sectors has increased due to these new regulations, thanks to which China has strengthened its position on global supply and also on value-added products. (Depraiter, 2025). This weaponization of supply and strategic uncertainty leads multinational corporations to wide vulnerability, forcing the US, EU, and Japan to take precautions by diversifying and maintaining rare earths (Hamed et al., 2024).

This means that geopolitical controls now operate not only as trade policy tools but also as mechanisms that directly shape the technological capabilities and production continuity of downstream industries, such as medical imaging. All of this demonstrates how global value chains are shaped by geopolitical decisions, making resource risks much broader problems.

2.4 Strategic Importance of REEs in Industry

As necessary and irreplaceable as they are within several relevant sectors, REEs are strategic materials. These materials are needed for magnets, alloys, and phosphors used for digital technologies, defense, and energy, but not in exaggerated quantities, nor is even a small dose enough (Guo & Guo, 2024; Schmid, 2019). REEs are essential in healthcare, more precisely in the functionality of some medical equipment. For MRI imaging to work, there is a need for gadolinium compounds, and again for high-field MRI machines, neodymium magnets are critical (Hamed et al., 2024). These materials present operational and clinical challenges for companies that manufacture medical devices, including Siemens Healthineers and GE Healthcare. Component redesign or replacement is especially expensive and time-consuming due to regulatory frameworks like the EU MDR and the FDA's material compliance standards. The testing burdens, verification processes, and risk-management responsibilities associated with these processes limit firms' flexibility in responding to supply disruptions. This means that REE-related supply shocks translate into direct technological rigidity: firms cannot quickly switch materials, redesign components, or adopt alternatives without facing years of regulatory approval.

Due to safety reasons and regulations, medical machinery cannot be modified and re-projected according to the deficiencies of rare materials. All of this, these disruptions, impact competitiveness and public health outcomes. As much as there is a lot of research to find materials that can replace REEs, the inadequate technology simply causes greater dependence on them (Hamed et al., 2024). This places REEs as crucial resources in fundamental fields for humans, making exporting an even more sensitive topic.

2.5 Mitigation Strategies

To the extent possible, governments and industries have and are seeking to reduce reliance on REEs. Among the different methods adopted, the most common are diversification, recycling, research and development, and policy tools.

To reduce dependence on China, several countries are looking, as far as economic resources and bottlenecks allow, for several mining projects. Two important examples are Australia, which has managed to increase production thanks to foreign projects, and the United States, which has decided to put national mines back into operation. As independent as both countries are trying to be, they have yet to ask China for help in the manufacturing phase (Mancheri, 2015; Hamed et al., 2024).

Another method, mainly adopted in the EU, is to recover REEs from products that are no longer functional, even though the amount of new products taking advantage of REEs is greater than the amount of end-of-life products. This research is based on magnets present in electric turbines and MRI machines (Schmid, 2019; Hamed et al., 2024).

As regards the production of materials similar to and substitutable for REEs, the research is still partial, as the alternatives produced are not entirely sustainable. As for medical machinery, they require very pure REEs, which is why the results obtained from research on magnets with low disposium and terbium content have not had great fame in the sector, but more in less powerful applications (Schmid, 2019).

As already demonstrated, national conservation and collaboration have been implemented in mining strategies, especially in the United States, Europe, and Japan. Although availability is lower than required, bilateral agreements and strategic reserves have been launched to ensure that supplies arrive from safe partners (Wang, 2018). As much as these mitigation measures can help, industries still find it difficult to solve problems, such as high costs, fragmented strategies that are unsuitable for covering all risks (Hosseini Shekarabi et al., 2025). These limitations are confirmed by recent quantitative and prospective assessments, which refine expectations regarding substitution and recycling. Realistic secondary-supply targets are supported by a 2023 material-flow analysis that estimates the size and makeup of European end-of-life Nd streams, elucidating recoverable stocks and the most recyclable product categories. In addition, a 2024 ex-ante LCA reveals scale-up dependencies (collection logistics, feedstock quality, and process integration) and demonstrates significant environmental benefits when comparing industrial-scale magnet-recycling routes (e.g., remelting + HDDR) with primary production.

In line with systemic risk diagnostics in the REE market, strict purity and performance requirements for REE-intensive medical-grade magnets continue to be a binding constraint on rapid substitution. These studies collectively imply that recycling and substitution are path-dependent but strategically significant; they show promise in the medium term but are unlikely to offset short-term supply shocks in the absence of inventory and diversification plans. This means that current mitigation measures remain partial and path-dependent: they reduce exposure but cannot eliminate dependence on Chinese refining, especially for high-purity applications like MRI magnets.

2.6 Theoretical Perspectives on Firm Responses

Strategies implemented by companies to avoid resource shocks are summarized as international business theories.

According to the Resource-Based View (RBV), REEs are rare, valuable, and unique sources without which many products could not work (Barney, 1991; Schmid, 2019). Dynamic capabilities (DCs) attest to the aptitude of companies not only to detect threats, exploit new possibilities, and re-adapt business processes, but also to spell out why some companies are able to adapt more easily through diversification or recycling (Teece, 2007; Hosseini Shekarabi et al., 2025). The OLI paradigm combines resource risk with globalization decisions by revealing methods used by companies, such as intermediate recycling or moving production to safer locations (Dunning, 1988; Nakano & Lau, 2019). While institutional theory explains how European companies move according to sustainability regulations, US companies are driven by national security imperatives. So this theory demonstrates how companies are driven by regulatory pressures that can change from region to region (Herold & Marzantowicz, 2023).

These frameworks summarize the commonalities and discrepancies that corporate resilience strategies have. Export restrictions and routing interruptions are examples of geopolitical shocks that act as external catalysts and jeopardize businesses' access to VRIN inputs like REE magnets (RBV). Businesses adjust their sourcing, technology, and recycling capabilities (also known as dynamic capabilities) in response to these shocks. While institutional contexts influence which responses are practical and noteworthy (e.g., European sustainability regulations vs. U.S. security-driven incentives), these adaptations manifest themselves in OLI choices, such as moving operations to jurisdictions with stricter quality control or internalizing magnet recovery to regain control over critical inputs. In summary: geopolitical shock → disruption of the market or logistics → reconfiguration of capabilities → decisions about internalization and location → institutionally shaped strategic differentiation. The aforementioned mechanism is reinforced by empirical research on healthcare supply chains during geopolitical disruptions, which demonstrates how regulatory variation and perishability constraints direct these choices toward cooperation, agility, and near-point-of-need solutions.

This means that the four theories together allow the study to link resource vulnerability, organisational capabilities, structural decisions, and institutional environments, providing a complete explanation for why firms facing the same shock respond differently.

2.7 Synthesis and Research Gap

Three key insights are revealed by the literature. First, China's dominance and political interventions have shaped the REE market, making it both strategically significant and structurally fragile. Second, businesses are exposed to systemic risks as a result of governments' and industries' fragmented, expensive, and only partially successful mitigation strategies. Third, theories of international business offer helpful but insufficient explanations:

RBV emphasizes the strategic importance of REEs, OLI stresses structural decisions, institutional theory emphasizes regulatory influences, and dynamic capabilities explain adaptation. The incomplete integration of these viewpoints is the research gap. Current research frequently treats firm-level responses, supply chain vulnerabilities, and geopolitical risks independently. In international business, a stronger link between firm-level strategic adaptation and systemic geopolitical uncertainties is required. The current study, which focuses on how healthcare multinationals react to shocks to the REE supply and what accounts for variations in their resilience strategies, is motivated by this gap.

2.8 Conclusion

According to the literature, REEs are essential strategic resources whose supply chains are extremely susceptible to market volatility and geopolitical threats. Diversification, recycling, substitution, and policy tools are some of the responses from governments and businesses, but they are still expensive and dispersed. Though they need to be integrated to properly explain resilience strategies, international business theories provide insight into various aspects of firm adaptation. The basis for examining how global healthcare companies, particularly GE Healthcare and Siemens Healthineers, handle rare earth supply disruptions is thus provided by this review.

3. THEORETICAL FRAMEWORK

The integrated conceptual framework created for the study is shown in **Figure 1**. According to the Resource-Based View (RBV), it illustrates how firm-level resource vulnerabilities are created by geopolitical shocks and risks associated with the rare earth market. These disruptions trigger adaptive processes that Dynamic Capabilities record. The Ownership–Location–Internalization (OLI) paradigm then interprets these adaptive processes to inform structural decisions. The framework also emphasizes how institutional contexts have a moderating effect, most notably the difference between US security-driven policies and EU sustainability standards, which results in distinct paths of firm resilience and strategic advantage.

The four theoretical lenses together form a causal mechanism that links geopolitical shocks to firm-level outcomes. External disruptions first generate resource vulnerability (RBV), as firms lose secure access to VRIN rare earth inputs. This vulnerability triggers adaptive processes (Dynamic Capabilities), through which firms sense risks, seize mitigation opportunities, and transform elements of their supply chain. These adaptive responses are then shaped by institutional contexts, which filter and constrain which strategic options are feasible or legitimate in each region. Finally, the OLI paradigm explains how firms translate these pressures into structural decisions on ownership, location, and internalisation. This mechanism—shock → vulnerability → capabilities → institutional filtering → structural choice → resilience—underpins the comparative analysis developed in the subsequent chapters.

Figure 1. Integrated Conceptual Framework of Firm Responses to Rare Earth Supply Shocks

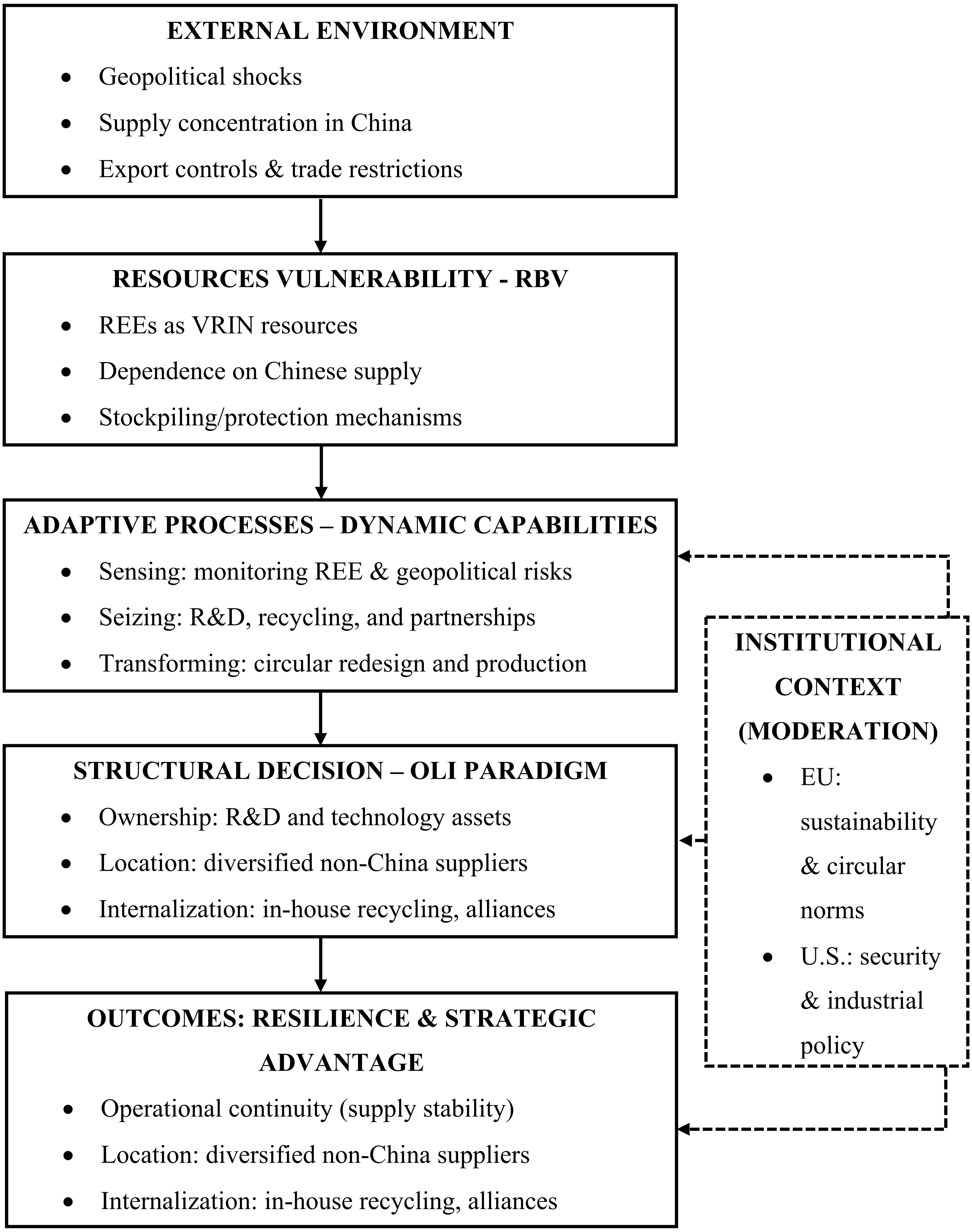

Table 1. Integrated Theoretical Framework: Lenses, Core Concepts, and Analytical Constructs

Theoretical Lens	Core Concepts & Purpose	Analytical Constructs	Analytical Focus / Expected Insight
Resource-Based View (RBV)	Firms gain sustained advantage through control of valuable, rare, inimitable, and non-substitutable (VRIN) resources (Barney, 1991). REEs are strategic VRIN inputs; supply shocks threaten competitiveness.	• Resource criticality • Resource protection mechanisms • Strategic value of material control	Identify degree of dependency and protection routines; evaluate whether control over REEs sustains competitive advantage.
Dynamic Capabilities (DC)	Firms sustain advantage under turbulence through sensing, seizing, and transforming capabilities (Teece, 2007). Explains how RBV resources are adapted under supply shocks.	• Sensing • Seizing • Transforming	Assess firms' ability to anticipate, respond, and reconfigure in response to REE disruptions; compare proactive (Siemens) vs. reactive (GE) adaptation.
Ownership–Location–Internalization (OLI) Paradigm	Explains international structural decisions on production and sourcing (Dunning, 1988). Shows where and how firms relocate or integrate operations to manage REE risks.	• Ownership advantages • Location advantages • Internalization advantages	Map geographic and structural adaptations; evaluate whether internationalization choices mitigate REE supply dependency.

Institutional Theory	Organizational behavior shaped by national and supranational norms, regulations, and legitimacy pressures (DiMaggio & Powell, 1983). Explains cross-national variance between GE and Siemens.	• Regulatory environment • Institutional pressures • Legitimacy-driven adaptation	Identify how differing institutional pressures shape strategic priorities (sustainability vs. security-driven responses).
Integrated Outcome: Firm Resilience & Strategic Advantage	Interaction of RBV (resources), DC (capabilities), OLI (structural decisions), and Institutional Theory (context) produces organizational resilience and competitive continuity.	• Operational resilience • Innovation continuity • Legitimacy & compliance	Synthesize cross-theoretical insights: evaluate which mechanisms most effectively explain resilience under geopolitical REE shocks.

4. RESEARCH DESIGN AND METHODOLOGY

4.1 Introduction

This chapter outlines the methodological approach used to investigate how GE Healthcare and Siemens Healthineers respond to the strategic risks arising from China's dominance in rare earth element (REE) markets. It explains how the study was designed, how the cases were selected, which types of data were used, and how those data were analysed to answer the research question. The chapter connects the theoretical foundations presented in Chapter 3 with the empirical analysis developed in Chapter 5. The methodology is grounded in a qualitative research tradition, which is appropriate for understanding complex organisational responses and interpreting how firms make sense of global political and supply chain disruptions (Eisenhardt, 1989; Yin, 2018). Instead of testing hypotheses, this approach seeks to build analytical insight by examining how firms react to REE supply shocks within their specific institutional environments. A comparative case structure enables the systematic exploration of differences and similarities between organisations facing the same type of external disruption.

The chapter proceeds in four stages. First, the research design is outlined and justified. Second, the rationale for selecting GE Healthcare and Siemens Healthineers as cases is presented. Third, the data sources used in the study are described, including corporate, policy, scientific, and industry documents. Finally, the data analysis strategy is explained, detailing how documents were examined, coded, and compared in line with the theoretical framework from Chapter 3. By clarifying each step of the research process, this chapter ensures transparency, methodological coherence, and alignment between the theoretical foundations, empirical evidence, and overall research objectives.

4.2 Research approach

This study adopts a qualitative research approach to examine how multinational healthcare firms interpret and respond to disruptions in rare earth element (REE) supply chains. A qualitative approach is appropriate because the research focuses on understanding organisational meanings, strategic responses, and adaptation processes rather than testing predetermined hypotheses. Qualitative research enables the exploration of complex phenomena embedded in geopolitical, regulatory, and technological contexts, where the interactions between firms and external shocks cannot be captured adequately through quantitative methods (Eisenhardt, 1989; Yin, 2018).

The approach supports an in-depth examination of how GE Healthcare and Siemens Healthineers make sense of, react to, and strategically adapt to REE-related vulnerabilities. Since REE disruptions involve interdependent factors—such as market concentration, institutional pressures, and technological constraints—a qualitative lens allows these dynamics to be analysed holistically. Instead of focusing on statistical generalisation, the study relies on analytical generalisation, in which theoretical insights are developed by linking empirical observations to the conceptual framework discussed in Chapter 3.

The qualitative approach also accommodates the use of multiple forms of secondary data, including corporate reports, policy documents, scientific studies, and industry analyses. Using diverse data sources strengthens the robustness of the findings through triangulation, allowing the cross-validation of emerging themes and reducing the risk of single-source bias (Bowen, 2009). This methodological choice aligns with the aim of understanding how firms interpret global disruptions and reconfigure their strategies in response to evolving resource dependencies. This design supports analytical generalisation rather than statistical generalisation, since the goal is to extend theoretical insights rather than to produce population-level claims.

By enabling a comprehensive and interpretive exploration of firm behaviour, the qualitative research approach provides the necessary depth to address the research question and supports the subsequent comparative case study design.

4.3 Research Design

This study employs a qualitative, comparative multiple-case study design to analyse how GE Healthcare and Siemens Healthineers respond to disruptions in rare earth element (REE) supply chains. A case study design is appropriate because the research investigates a contemporary, complex phenomenon—firm-level strategic adaptation to geopolitical resource shocks—within its real-world context, where organisational behaviour cannot be separated from institutional, technological, and market conditions (Yin, 2018). Case studies allow the researcher to examine causal mechanisms, trace processes, and develop theoretically informed explanations of organisational responses.

The design is explicitly comparative. Following Eisenhardt (1989) and Yin (2018), a comparative case study allows for the systematic exploration of similarities and differences across cases exposed to comparable external pressures. Both GE Healthcare and Siemens Healthineers operate in the same industry, face identical material dependencies, and experience the same REE disruptions; however, they are embedded in distinct institutional environments. This contrast makes the comparative design suitable for identifying how institutional and organisational factors shape divergent resilience strategies.

The comparative logic follows a theory-driven replication strategy. Each case is first analysed independently to identify patterns related to resource vulnerabilities, adaptive capabilities, structural decisions, and institutional constraints. The two cases are then compared to assess whether similar external shocks lead to similar or different adaptive responses, and how the theoretical lenses introduced in Chapter 3 (RBV, Dynamic Capabilities, OLI, and Institutional Theory) help explain these patterns.

This design does not aim for statistical generalisation but for analytical generalisation, in which empirical insights are interpreted in light of established theoretical frameworks. By integrating cross-case comparison with theory-driven constructs, the research design provides a rigorous basis for explaining firm-level variation in responses to global REE disruptions. A simplified diagram summarising the research process is included to enhance transparency and illustrate the sequencing of design, data collection, and analysis steps.

4.4 Case Selection and Rationale

The study employs purposeful, theory-driven case selection, identifying GE Healthcare and Siemens Healthineers as two information-rich cases that enable the investigation of how multinational firms respond to rare earth element (REE) supply disruptions. Purposeful sampling is appropriate for qualitative case study research because it allows the researcher to select cases that are most relevant for answering the research question and for extending theoretical understanding of the phenomenon under investigation (Eisenhardt, 1989; Yin, 2018).

The selection of GE Healthcare and Siemens Healthineers is based on three methodological criteria.

1. **Shared Exposure to the Same External Shock**

Both firms are global leaders in medical imaging and rely heavily on REE-intensive components such as neodymium-iron-boron (NdFeB) magnets and gadolinium-based materials. This results in:

- comparable technological dependence on REEs,
- similar vulnerability to supply chain disturbances,

- exposure to identical geopolitical shocks — including the 2010–2011 Chinese export quotas and the 2024–2025 export licensing controls.

Selecting cases with similar external conditions ensures that observed differences in firm responses cannot be attributed to different levels of exposure but instead reflect organisational and institutional variation.

2. **Contrasting Institutional Environments**

Although facing identical REE-related pressures, the two firms operate in distinct institutional contexts:

GE Healthcare is embedded in the U.S. regulatory environment, where REE supply security is framed predominantly through national security, reshoring, and strategic autonomy priorities.

Siemens Healthineers operates within the European Union, where policy frameworks emphasise sustainability, circular economy principles, and environmental compliance.

These contrasting institutional settings provide an ideal basis for examining how regulatory and political environments shape firm-level resilience strategies. This aligns with the theoretical expectation—derived from Institutional Theory—that organisational behaviour varies systematically across different institutional contexts.

3. **Analytical Relevance and Data Availability**

Both companies offer extensive public documentation relevant to the study's objectives, including sustainability reports, environmental product documentation, circular economy policies, and strategic disclosures. In addition, both firms are frequently referenced in policy papers, scientific literature, and industry analyses concerning REE dependencies in medical imaging. This makes them analytically suitable cases for triangulating data sources and conducting in-depth qualitative analysis.

Case Design Logic

Together, GE Healthcare and Siemens Healthineers constitute a **most-similar systems design**: two firms operating in the same sector, producing similar products, subject to the same REE shocks, but embedded in different institutional frameworks. This design supports the comparative logic required to identify how institutional context, organisational capabilities, and structural decisions produce divergent strategic responses to REE disruptions.

Thus, the selected cases allow the study to meet its objective: explaining not only how firms respond to REE supply risks, but why their resilience strategies differ.

4.5 Data Sources

This research relies exclusively on secondary qualitative data. Secondary data is appropriate for this study because it provides access to organisational, policy, and industry information that documents firm strategies, regulatory developments, and market dynamics over time. Using multiple types of documents enables triangulation, strengthens validity, and supports a detailed examination of how GE Healthcare and Siemens Healthineers respond to REE-related disruptions (Bowen, 2009).

The dataset covers the period from 2010 to 2024. This timeframe captures both the 2010–2011 Chinese export quota disruptions and the more recent 2024–2025 export licensing controls, allowing the analysis to track how firm strategies evolved across distinct geopolitical shocks.

To ensure transparency and systematic organisation, the data sources are grouped into four categories:

Table 2. Categories of Secondary Data Used in the Study

Category	Purpose in the Analysis

Corporate Reports	Identify firm strategies, circularity initiatives, supplier diversification, and organisational narratives.
Policy and Regulatory Documents	Understand institutional pressures, regulatory frameworks, and national resource-security priorities.
Scientific and Technical Literature	Provide evidence on REE market structure, material constraints, and technological limits relevant to medical imaging.
Industry and Media Sources	Track market volatility, document geopolitical shocks, and observe immediate industry responses.

Corporate reports provide insight into how each company publicly communicates and documents its sustainability measures, recycling initiatives, material strategies, and supply chain adaptations. Policy documents from U.S. and EU institutions clarify the regulatory environments in which each firm operates, allowing institutional differences to be incorporated into the analysis. Scientific publications supply technical and market-based evidence regarding REE availability, magnet performance requirements, and the feasibility of recycling or substitution—factors that directly shape organisational responses.

Industry analyses and reputable media articles were included to contextualise geopolitical events and capture real-time market reactions, particularly regarding the 2024–2025 export licensing controls announced by China's Ministry of Commerce.

Using a diverse set of documents strengthens the credibility of the findings by enabling cross-validation across independent sources. The variety of document types also reflects the multi-layered nature of REE disruptions, which simultaneously involve corporate strategy, resource markets, regulatory dynamics, and geopolitical developments.

4.6 Data Analysis Method

The analysis followed a structured and theory-informed qualitative procedure designed to link the empirical data to the conceptual framework outlined in Chapter 3. Because the goal of the study is to explain differences in firm-level responses to REE supply disruptions, the analytical process combined within-case analysis, cross-case comparison, and deductive coding based on established theoretical constructs (Eisenhardt, 1989; Yin, 2018). The analysis proceeded through four systematic stages.

Stage 1: Familiarisation and Initial Review

All collected documents were read in full to develop a comprehensive understanding of firm strategies, policy contexts, and market developments related to rare earth elements. During this stage, attention was given to identifying preliminary patterns such as supply chain vulnerabilities, recycling initiatives, evidence of regulatory influence, and early indications of firm-level adaptation. This stage ensured that subsequent coding was grounded in a thorough understanding of the dataset.

Stage 2: Development of a Theory-Driven Codebook

In line with the deductive approach recommended for theory-informed case studies, the initial set of codes was derived from the analytical dimensions of the conceptual framework: the Resource-Based View, Dynamic Capabilities, the OLI paradigm, and Institutional Theory. Each theoretical lens provided a set of analytical categories used to organise and interpret the data. The table below summarises the key deductive codes:

Table 3. Deductive Codes Based on Theoretical Framework

Theoretical Lens	Deductive Codes
RBV	Resource criticality; VRIN dependence; vulnerability to REE shocks
Dynamic Capabilities	Sensing; seizing; transforming; responsiveness; adaptation speed
OLI Paradigm	Location decisions; internalisation of activities; ownership advantages; supplier diversification
Institutional Theory	Regulatory pressures; legitimacy requirements; sustainability mandates; national security framing

These theoretical categories served as the primary structure for coding, ensuring that the analysis remained aligned with the research question and conceptual framework.

Stage 3: Coding and Within-Case Analysis

All documents were systematically coded using the deductive codebook. This enabled the identification of themes tied to each firm's exposure to REE disruptions, strategic responses, and institutional constraints. For each case, coded segments were examined to identify patterns related to resource dependence, adaptive behaviours, production decisions, and sustainability initiatives.

Within-case analysis produced detailed case narratives for GE Healthcare and Siemens Healthineers, highlighting the internal logic of each firm's strategic response to REE disruptions.

Stage 4: Cross-Case Comparison and Pattern Matching

Following Yin's (2018) replication logic, findings from each case were compared to identify convergent and divergent patterns. This stage assessed whether similar external shocks produced similar or different strategic responses across the two firms. Special attention was given to differences in timing (reactive vs. proactive), depth of circularity integration, diversification strategies, and the influence of institutional environments.

This cross-case comparison generated the analytical insights presented in Chapter 5, allowing conclusions to be drawn regarding how external pressures, organisational capabilities, and institutional contexts interact to shape firm resilience.

Analytical Generalisation

Rather than seeking statistical generalisation, the study employs analytical generalisation by linking empirical observations to theoretical constructs. The combination of deductive coding, within-case analysis, and cross-case comparison strengthens theoretical explanation and supports the development of nuanced insights into how healthcare multinationals navigate REE supply shocks.

4.7 Company Backgrounds

Brief contextual profiles of the selected firms are provided to clarify their relevance to the research design. GE Healthcare and Siemens Healthineers are two of the largest global manufacturers of medical imaging technologies, particularly magnetic resonance imaging (MRI) and computed tomography (CT) systems. Both companies operate internationally and maintain substantial production, R&D, and supply chain activities across multiple regions, making them representative actors within the medical technology sector.

GE Healthcare, headquartered in Chicago (USA), is a major producer of MRI, CT, ultrasound, and diagnostic imaging technologies. Its product portfolio relies on components that require high-performance rare earth materials, particularly NdFeB magnets and gadolinium-based compounds. GE's global operations and strong presence in the U.S. market position it within an institutional environment characterised by national security–oriented critical mineral policies.

Siemens Healthineers, based in Erlangen (Germany), is a leading European medical technology firm with a similarly extensive imaging portfolio. Like GE Healthcare, it manufactures REE-intensive MRI and CT systems. Siemens operates predominantly within the European Union, where regulatory frameworks emphasise sustainability, circularity, and strategic autonomy in relation to critical raw materials.

These concise backgrounds establish the relevance of both firms as cases that share technological requirements and exposure to REE supply risks, while operating under different institutional conditions. Detailed company profiles and strategic developments are presented in Chapter 5, where they support the empirical analysis.

4.8 Summary

This chapter presented the methodological foundation of the study and demonstrated how the research design aligns with the objective of explaining differences in firm-level responses to rare earth element (REE) supply disruptions. The chapter outlined the use of a qualitative, comparative multiple-case study design, justified through its suitability for examining complex organisational behaviour within real-world geopolitical and institutional contexts. The rationale for selecting GE Healthcare and Siemens Healthineers was grounded in purposeful sampling logic, emphasising their shared technological dependence on REEs and their contrasting institutional environments.

The chapter also detailed the secondary data sources used in the analysis, drawing on corporate documents, policy frameworks, scientific literature, and industry reports to ensure triangulation and analytical robustness. The data analysis method followed a structured, theory-driven procedure involving deductive coding, within-case analysis, and cross-case comparison, guided by the theoretical lenses introduced in Chapter 3.

By clarifying each methodological step and demonstrating how it supports analytical generalisation, the chapter establishes a transparent and coherent foundation for the empirical findings. The next chapter applies this methodological framework to examine how GE Healthcare and Siemens Healthineers interpret, manage, and respond to REE-related disruptions, and what accounts for the divergence in their resilience strategies.

5. FINDINGS AND ANALYSIS

This chapter presents the empirical findings of the study and analyzes them through the theoretical lens developed in Chapter 3. Building directly on the methodological choices outlined in Chapter 4, it integrates evidence from company reports, policy documents, industry analyses, and peer-reviewed research to examine how GE Healthcare and Siemens Healthineers respond to rare earth element (REE) disruptions driven by China's structural dominance and geopolitical intervention. The analysis follows the logic of replication outlined by Yin (2018), treating the two cases as theoretically informed contrasts rather than isolated narratives.

The chapter proceeds in four steps. First, it outlines the external disruptions and material vulnerabilities confronting the medical imaging sector, clarifying the shared exposure of both firms to REE supply shocks. Second, each firm is analysed individually to show how it interprets and responds to these vulnerabilities through different forms of adaptive capabilities, strategic reconfiguration, and institutional alignment. Third, a structured comparison highlights the strategic divergence between the two companies. Finally, the findings are interpreted through the combined theoretical lenses to identify which mechanisms best explain differing resilience outcomes.

The goal is not only to describe organisational responses but also to interpret them in context—linking external pressures to internal capabilities and decision-making logics. High citation density is employed to ensure rigorous triangulation across corporate, scientific, and policy-based evidence.

5.1 Evidence of Rare Earth Disruptions Affecting Global Medical Imaging

Rare earth element (REE) disruptions form the structural backdrop against which both GE Healthcare and Siemens Healthineers operate. Although the two firms differ in their institutional environments and strategic responses, they share exposure to the same global supply risks. This section summarises the essential empirical evidence on market concentration, geopolitical interventions, and medical-grade material constraints, establishing the common vulnerability that underpins the subsequent case analyses.

5.1.1 China's Market Dominance and Structural Concentration

Despite their geological abundance, economically viable REE deposits and, crucially, refining capacity remain highly concentrated. China controls roughly 60% of global mining output and between 85% and 90% of refining capacity, largely due to decades of state-supported industrial policy and more flexible historical environmental regulations (Guo & Guo, 2024; Schmid, 2019). Even producers outside China often send ores to Chinese refiners because alternative facilities are insufficient to meet global demand (Oxford Institute for Energy Studies, 2023). Since high-performance NdFeB magnets require consistent purity and specialised metallurgical capabilities, this concentration creates systemic dependence for downstream industries, including medical imaging. This section builds on but does not repeat the literature review; rather, it establishes the specific empirical conditions that frame both firms' strategic responses.

5.1.2 Export Controls and Geopolitical Shocks

China's dominant position has enabled it to shape global supply conditions through administrative controls and export restrictions. Two interventions are particularly relevant. First, the 2010–2011 export quota reductions significantly increased prices for dysprosium and terbium, disrupting production schedules for manufacturers of MRI and CT components (Mancheri, 2015; Hamed et al., 2024).

Second, the 2024–2025 export licensing requirements under Announcement No. 18 introduced renewed uncertainty, affecting materials such as samarium, gadolinium, and dysprosium (Depraiter et al., 2025). While not halting exports entirely, the licensing regime generated supply delays and market volatility; GE Healthcare's stock price decline at the announcement illustrates the immediate operational concerns faced by manufacturers (Investing.com, 2025). Siemens Healthineers also acknowledged the regulatory shift as a long-term strategic risk, despite its more diversified sourcing base.

5.1.3 Market Volatility and Systemic Supply Chain Fragility

The broader REE market is characterised by persistent price volatility, with financial analyses showing sensitivity to geopolitical tensions and speculation (Wan et al., 2025). For firms producing MRI and CT systems—where magnets require stable quality, precise alloy composition, and long manufacturing lead times—such volatility complicates planning, inventory management, and contractual supply arrangements. Supply chain research identifies REEs as a case of global systemic risk, whereby disruptions originating in one region propagate across multiple tiers with limited buffering capacity (Fan & Stevenson, 2018; Nakano & Lau, 2019).

5.1.4 Vulnerabilities Specific to Healthcare Imaging Technologies

Medical imaging firms face heightened exposure because their core technologies depend on REE-intensive components with strict performance and regulatory requirements. NdFeB magnets, often doped with dysprosium for thermal stability, are indispensable for MRI systems; gadolinium compounds remain essential for contrast enhancement (Chaban et al., 2024; Hamed et al., 2024). Regulatory frameworks such as the EU MDR and U.S. FDA impose rigorous testing and re-certification requirements, meaning even minor material substitutions can take years to validate (Leppälä et al., 2023). Research on low-dysprosium or alternative magnet chemistries shows progress for sectors like electric mobility, but these designs do not yet meet the stability and purity thresholds required for medical imaging

(Rizos et al., 2022; Ghorbani, 2025). Furthermore, installed MRI and CT fleets require long-term maintenance, creating ongoing demand for compatible REE-based parts. Together, these factors show not only that the sector is exposed to REE shocks, but that firms have structurally limited room to manoeuvre, which is what makes differences in strategic responses analytically meaningful.

5.2 GE Healthcare: Exposure, Strategic Adaptation, and Resilience

This section examines how GE Healthcare interprets and responds to rare earth element (REE) disruptions, building on the sector-wide vulnerabilities outlined in Section 5.1. It analyses the company's exposure to material dependencies, the evolution of its risk-mitigation measures, and the institutional factors shaping its approach. By tracing GE Healthcare's strategies across recycling, diversification, and domestic policy alignment, the section highlights the firm's predominantly reactive adaptation pattern and sets the foundation for the comparative analysis developed later in the chapter.

5.2.1 Exposure to Rare Earth Dependencies

GE Healthcare's product portfolio—particularly its MRI systems—relies heavily on rare earth magnets composed of neodymium, iron, and boron (NdFeB), often doped with dysprosium to ensure thermal stability (GE Healthcare, 2024; Hamed et al., 2024). As outlined in Section 5.2, these materials are subject to extreme concentration risks due to China's dominant position in mining and refining (Guo & Guo, 2024; Schmid, 2019). Consequently, GE Healthcare's exposure is not only material-specific but also structurally embedded in the global REE supply chain.

Empirical evidence confirms that GE Healthcare has faced multiple waves of disruption. During the 2010–2011 export quota crisis, the company reported input cost increases and delivery delays due to shortages of dysprosium and neodymium (Hamed et al., 2024). More recently, China's Announcement No. 18 in 2025 triggered renewed concerns, and market reactions were immediate: GE Healthcare's stock declined sharply as investors anticipated higher production costs and constrained access to essential materials (Investing.com, 2025). The firm's U.S.-based production footprint amplifies this risk. Unlike Siemens Healthineers, which sources more magnets through diversified European and Asia-Pacific networks, GE Healthcare remains heavily tied to suppliers whose refining processes depend directly or indirectly on Chinese facilities (U.S. Department of Energy, 2022). This structural dependence has shaped the company's need to pursue resilience strategies that compensate for limited supply optionality.

Unlike the literature review, which presented sector-wide constraints, this subsection specifies how these constraints materialise within GE's particular supply architecture, making them directly relevant to the firm's subsequent strategic choices.

5.2.2 Immediate and Reactive Responses to Supply Disruptions

The empirical data shows that GE Healthcare's approach to rare earth risk has historically been reactive, particularly when compared with Siemens Healthineers. Following the 2010–2011 crisis, GE focused primarily on short-term actions to stabilise production, including more frequent communication with suppliers, adjustments to procurement schedules, and ad hoc mitigation plans (Hamed et al., 2024). These actions stabilised operations but did not alter the company's structural dependence.

Similarly, the 2024–2025 licensing measures introduced by China prompted rapid operational reassessments. GE's internal reports indicate intensified monitoring of supply chain risks and closer coordination with U.S. government bodies involved in critical mineral assessments (GE Healthcare, 2025). However, these responses were again triggered by events rather than anticipated through long-term strategic foresight.

This reactive posture aligns with characteristics identified in the supply chain resilience literature, where firms with limited sensing capabilities exhibit delayed adaptation until disruptions materialise (Fan & Stevenson, 2018; Nakano & Lau, 2019). GE Healthcare's adaptations were therefore necessary responses to immediate scarcity but did not fundamentally shift the structure of its supply relationships in the short term.

5.2.3 Recycling and Circularity Programs

One of GE Healthcare's most significant resilience initiatives is its investment in MRI magnet recycling, which has become a central component of its sustainability and supply chain strategy. According to GE's Environmental Product Collateral, the company has increasingly integrated recycled REEs into its manufacturing processes through end-of-life magnet recovery, refurbishment of superconducting magnet assemblies, and more systematic extension of product lifecycles (GE Healthcare, 2024; GE Healthcare, 2025). Academic studies further support the viability of magnet recycling as a resilience mechanism: hydrometallurgical and pyrometallurgical processes enable the recovery of neodymium and dysprosium at high purity levels, demonstrating both technical feasibility and economic potential (Bandara et al., 2014; München et al., 2021). This alignment between industrial practice and scientific evidence strengthens the credibility of GE's approach.

Although GE's recycling programs reduce dependence on primary Chinese REE sources and provide partial control over critical material inputs, their impact remains necessarily limited. Literature on REE supply chains emphasises that secondary recovery cannot meet total demand for high-performance magnets in the near term, particularly given the stringent purity and stability requirements of medical imaging technologies (Rizos et al., 2022; Ghorbani, 2025). Thus, recycling constitutes an important but incomplete component of GE Healthcare's resilience strategy.

5.2.4 Supplier Diversification: Incremental and Constrained Progress

Beyond recycling, GE Healthcare has pursued diversification strategies aimed at reducing dependence on Chinese suppliers. This includes identifying alternative sources for refined rare earth oxides and magnets in regions such as the U.S., Japan, and Australia (U.S. DOE, 2024). However, diversification is limited by two structural constraints:

1. **Global refining concentration:**

Even non-China miners send their ores to Chinese processing facilities (Oxford Institute for Energy Studies, 2023).

2. **Performance requirements for medical magnets:**

Few producers can manufacture magnets that meet MRI specifications (Leppälä et al., 2023). As a result, GE Healthcare's diversification is slower and narrower than that of Siemens Healthineers. Evidence from U.S. government documents shows GE participating in national initiatives to develop domestic magnet supply chains, including collaboration with the Department of Energy's Critical Materials Institute (U.S. DOE, 2022). These programs represent medium-term strategic investments rather than immediate solutions.

Overall, GE's diversification strategy is best characterised as incremental rather than transformative. It expands supplier optionality, but structural dependence on Chinese refining persists.

5.2.5 U.S. Institutional and Policy Influences on Strategy

GE Healthcare's strategic trajectory is strongly shaped by its U.S. institutional environment. Federal policies emphasising national security, reshoring, and industrial competitiveness create powerful incentives for firms to prioritise domestic capability-building over global diversification (U.S. DOE, 2024; CRS, 2023). Programs such as the U.S. Critical Minerals Strategy, Defense Production Act allocations, and federal grants for domestic magnet development have encouraged GE to align its resilience efforts with national policy objectives. This alignment is evident in the firm's collaborations with U.S. government agencies, particularly in areas such as REE recycling, substitute material research, and domestic supply chain development (GE Healthcare, 2025).

Compared with the European Union's sustainability-oriented institutional environment, the U.S. system places less emphasis on circularity and eco-design and more on security-driven mitigation measures. GE Healthcare's focus on recycling, domestic partnerships, and incremental supplier diversification reflects this broader institutional context. The firm's adaptive behaviour therefore mirrors U.S. regulatory and normative priorities, reinforcing a strategy centred on domestic resilience rather than systemic transformation.

5.3 Siemens Healthineers: Exposure, Strategic Adaptation, and Resilience

This section explores Siemens Healthineers' strategic response to REE supply disruptions and contrasts its adaptation trajectory with that of GE Healthcare. Drawing on evidence from sustainability reports, procurement strategies, and technological initiatives, it examines how Siemens Healthineers has proactively diversified suppliers, embedded circularity practices, and invested in material innovation. By emphasising early sensing and system-level redesign, this section provides the basis for understanding why Siemens demonstrates higher resilience under the same structural constraints faced by GE Healthcare.

5.3.1 Exposure to Rare Earth Dependencies

Siemens Healthineers' dependence on rare earth materials mirrors that of GE Healthcare, as its MRI and CT systems rely on NdFeB magnets with high neodymium and dysprosium content, gadolinium-based contrast agents, and rare earth phosphors used in imaging displays. These materials are essential for achieving magnetic field strength, thermal stability, and diagnostic image clarity, as confirmed by industry and scientific studies (Hamed et al., 2024; Chaban et al., 2024). Like GE, Siemens faced price shocks and supply constraints during the 2010–2011 disruption (Mancheri, 2015; Schmid, 2019). However, Siemens differs significantly in how it interpreted this event: rather than treating it as a temporary crisis, the company viewed it as evidence of long-term structural vulnerability and began adjusting its supply chain in the early 2010s (Siemens Healthineers, 2024). Thus, Siemens faces similar material exposure but responds along a markedly different temporal trajectory. This clarifies that the purpose of this exposure subsection is not to repeat prior information, but to establish the baseline against which Siemens' proactive response strategy is interpreted.

5.3.2 Early and Proactive Supplier Diversification

Following the 2010 crisis, Siemens Healthineers initiated a strategic reconfiguration of its supply base to reduce reliance on Chinese refining. European Commission reports at the time underscored the need for European manufacturers to diversify critical material supply chains, and Siemens responded by expanding procurement routes across Europe, the United States, and Australia. These efforts included exploring sourcing opportunities linked to emerging European refining initiatives, leveraging non-Chinese producers such as Lynas in Australia, and engaging with U.S.-based magnet development programmes (European Commission, 2023; ERECON, 2023; Siemens Healthineers, 2024). Unlike GE Healthcare, whose diversification efforts remain heavily tied to U.S. policy mechanisms, Siemens integrated multi-regional sourcing into its long-term strategy, allowing it to enter the 2024–2025 disruption period with greater flexibility and reduced single-country exposure.

5.3.3 Advanced Recycling, Refurbishment, and Circularity Integration

Circular economy practices represent one of Siemens Healthineers' strongest and most distinctive resilience mechanisms. The company deploys a multi-tiered circularity model that extends across the entire imaging system lifecycle. At the magnet level, Siemens systematically extracts NdFeB permanent magnets from end-of-life MRI and CT systems through dismantling procedures designed to preserve magnetic integrity and maximise recovery yields (Siemens Healthineers, 2024). At the system level, the company remanufactures complete MRI and CT units through programmes such as “Smart Remote Services” and its “Refurbished Systems” portfolio, which significantly extend equipment lifecycles and directly reduce reliance on primary REE extraction. At the component level, Siemens applies circular principles across gradient systems, coils, cooling units, electronics, and associated subsystems, supported by a reverse-logistics infrastructure that enables used parts to be returned to specialised European refurbishment facilities.

Evidence from Siemens’ sustainability documentation shows that recycled or refurbished components constitute a growing share of its imaging portfolio, indicating that circularity is embedded not only in isolated processes but in the wider organisational model (Siemens Healthineers, 2024). This breadth stands in contrast to GE Healthcare’s more narrowly focused magnet-level recycling initiatives. Whereas GE’s approach contributes meaningfully to risk mitigation, Siemens’ multi-level system extends circularity far deeper into the product architecture and value chain.

Scientific literature reinforces the strategic importance of Siemens’ approach. Studies demonstrate that end-of-life NdFeB magnets represent one of the most viable secondary sources of rare earths for high-performance applications, yet only a small number of industries have succeeded in operationalising large-scale recovery (München et al., 2021; Rizos et al., 2022). Siemens’ ability to integrate magnet extraction, whole-system refurbishment, and component-level recycling therefore places it ahead of broader sectoral trends.

Moreover, the model aligns strongly with EU circular economy and sustainability directives, which emphasise material efficiency, recoverability, and lifecycle extension as core industrial priorities (European Commission, 2020). Siemens' circularity strategy therefore serves not only as a resilience mechanism but also as a key channel through which the firm complies with, and capitalises on, European regulatory frameworks.

5.3.4 R&D for Material Innovation and Low-REE Technologies

Siemens Healthineers distinguishes itself through substantial long-term R&D investment aimed at reducing dependence on vulnerable rare earth inputs and restructuring future MRI magnet architectures. Empirical evidence reveals three major innovation streams. First, the company is engaged in collaborative research on reduced-dysprosium magnetic materials, seeking to lower reliance on one of the most geopolitically constrained heavy REEs while maintaining the thermal stability required for medical-grade MRI performance (Rizos et al., 2022). This work is particularly significant given dysprosium's disproportionate sensitivity to Chinese export controls and its centrality to high-temperature magnet performance (Schmid, 2019). Second, Siemens is developing a €250 million magnet manufacturing facility in Oxfordshire, scheduled to be operational in 2027. This initiative represents a structural reconfiguration of the supply chain toward European-based magnet production and directly supports EU strategic autonomy objectives under the Critical Raw Materials Act (InsiderMedia, 2025; European Commission, 2023). Third, Siemens applies eco-design principles across early product development phases, enabling imaging systems that consume fewer raw materials, exhibit higher reparability and recyclability, and are more easily integrated into circular refurbishment cycles (Siemens Healthineers, 2024).

Although scientific literature underscores that full material substitution in MRI magnets remains highly complex due to stringent electromagnetic and thermal requirements

(Ghorbani, 2025; Leppälä et al., 2023), Siemens' approach demonstrates strong transforming capabilities as defined in the Dynamic Capabilities framework. Rather than treating REE constraints as a condition to be mitigated through short-term responses, Siemens invests in redesigning product architectures to structurally reduce long-term vulnerability. Its multi-stream innovation strategy therefore reflects a deliberate effort to reposition the firm for a future in which rare earth volatility persists and where alignment with European sustainability and strategic autonomy goals is likely to increasingly influence competitiveness.

5.3.5 Production Flexibility and European Manufacturing Strategy

Siemens Healthineers benefits from a geographically flexible production network distributed across multiple European sites. Its modular manufacturing lines are designed to adapt to fluctuations in material availability, supported by close integration with nearby R&D centres and European supplier ecosystems (Siemens Healthineers, 2024). This configuration aligns with EU industrial strategies that promote regionalised supply chains and reduced dependence on external actors (European Commission, 2023). Such geographic dispersion and modularity enhance Siemens' ability to absorb disruptions compared with GE Healthcare's more U.S.-centred and less flexible production footprint.

5.3.6 EU Institutional and Regulatory Influences

Siemens Healthineers' proactive strategy is strongly shaped by the European institutional environment, which emphasises sustainability, circularity, and strategic autonomy. The EU's Circular Economy Action Plan and associated ecodesign directives incentivise manufacturers to reduce raw material intensity, improve recyclability, and maximise end-of-life recovery (European Commission, 2020). Concurrently, policies under the European Industrial Strategy encourage firms to reduce reliance on Chinese REE refining and strengthen Europe's internal capacity for magnet production (European Commission, 2023). Siemens also faces substantial environmental legitimacy pressures from European regulatory bodies, consumers, and investors, which further reinforce sustainability-led innovation (Yu et al., 2023). Together, these institutional forces push Siemens toward early diversification, circularity integration, and material innovation—strategies that differ fundamentally from the security-oriented U.S. policy environment shaping GE Healthcare.

5.4 Comparative Analysis: Diverging Resilience Strategies

Having analysed each firm individually, this section compares GE Healthcare and Siemens Healthineers to identify patterns of convergence and divergence in their strategic responses. Despite operating in the same industry and facing identical REE-related vulnerabilities, the firms exhibit markedly different trajectories with respect to timing, diversification, circularity, innovation, and institutional alignment. By systematically juxtaposing these dimensions, the section clarifies the mechanisms that account for the stronger resilience demonstrated by Siemens Healthineers and prepares the ground for the theoretical integration in Section 5.5.

Table 4. Strategic Differences Between GE Healthcare and Siemens Healthineers

Analytical Dimension	GE Healthcare	Siemens Healthineers
Timing of Strategic Adjustment	Adjusts primarily after disruptions materialise, focusing on short-term stabilisation rather than early structural change.	Interprets disruptions as long-term indicators of structural risk and integrates early, anticipatory adjustments into long-term planning.
Diversification of Supply Chain	Pursues gradual and largely U.S.-centred diversification; progress is constrained by global reliance on Chinese refining and limited supplier options for medical-grade magnets.	Diversifies earlier and across Europe, the U.S., and Australia, achieving broader regional coverage and reducing single-country dependence.

Depth of Circularity and Recycling Integration	Circularity efforts focus mainly on MRI magnet recycling and end-of-life material recovery, providing resilience but covering a narrow part of the system.	Implements circularity across the entire imaging lifecycle, including magnet extraction, system refurbishment, and reverse logistics, significantly reducing primary REE dependence.
Innovation and Material Substitution	Engages in collaborative research but invests less in redesigning magnet architectures; technological substitution remains limited due to strict medical requirements.	Invests heavily in low-REE magnet R&D, eco-design, and a new European magnet facility, positioning the firm for long-term structural reduction of REE vulnerability.
Production Flexibility	U.S.-centred manufacturing footprint limits geographic and supplier flexibility, reinforcing exposure to upstream constraints.	Modular and geographically distributed European production network allows quicker adjustments to material availability and regional supply shifts.
Institutional Alignment	Strategy aligns with U.S. policy priorities—national security, reshoring, and domestic capability-building—leading to resilience framed around recycling and domestic partnerships.	Strongly aligned with EU sustainability and circular-economy regulations, which incentivise early diversification, lifecycle efficiency, and long-term material innovation.

Taken together, the evidence suggests that Siemens Healthineers consistently interprets REE disruptions as indicators of long-term structural risk, enabling earlier and more comprehensive adaptation. GE Healthcare, by contrast, tends to adjust primarily when disruptions have already materialised, resulting in narrower diversification and more incremental innovation. The institutional environments in which both firms operate reinforce this divergence: U.S. policy incentives drive GE towards domestic resilience and recycling initiatives, whereas EU regulations encourage Siemens to prioritise circularity, sustainability, and strategic autonomy. Consequently, Siemens achieves more deeply embedded and anticipatory resilience, while GE's progress remains meaningful but more constrained.

5.5 Integration with Theoretical Framework

This section interprets the empirical findings through the theoretical lens established in Chapter 3, integrating insights from the Resource-Based View, Dynamic Capabilities, the OLI paradigm, and Institutional Theory. By mapping each firm's behaviour onto these frameworks, the section explains not only how GE Healthcare and Siemens Healthineers responded to REE disruptions but why their strategic pathways diverge. This theoretical synthesis links firm-level evidence to broader international business mechanisms, offering a comprehensive explanation of resilience differences.

5.5.1 Resource-Based View (RBV): Strategic Vulnerability of VRIN Inputs

The RBV highlights why both firms face a shared and unavoidable vulnerability. Rare earth magnets and gadolinium-based materials constitute VRIN resources because they are essential for MRI and CT performance, produced by a very limited number of global refiners, reliant on specialised metallurgical expertise, and subject to strict regulatory thresholds that restrict substitution (Barney, 1991; Chaban et al., 2024; Guo & Guo, 2024; Leppälä et al., 2023). China's control of 85–90% of refining capacity amplifies this dependence and exposes both GE Healthcare and Siemens Healthineers to systemic supply risks (Schmid, 2019; Mancheri, 2015). RBV therefore explains the strategic importance of securing REE access, but on its own does not explain why Siemens is systematically more resilient than GE, since both firms rely on the same VRIN inputs.

5.5.2 Dynamic Capabilities: Sensing, Seizing, and Transforming Under Disruption

Dynamic Capabilities theory explains how differences in sensing, seizing, and transforming capabilities shape the firms' adaptation to REE shocks (Teece, 2007). Siemens Healthineers demonstrates strong sensing capabilities, interpreting the 2010 export restrictions as an early warning signal and initiating supplier diversification, circularity programmes, and R&D into alternative magnet compositions well before further disruptions emerged (Mancheri, 2015; Siemens Healthineers, 2024). Its seizing and transforming capabilities are reflected in its system-wide refurbishment initiatives, low-REE magnet research, and the development of a new European magnet manufacturing base. GE Healthcare's capabilities are more reactive: significant adjustments tend to occur only after disruptions materialise, and seizing activity is strongly shaped by U.S. policy incentives, with transformation centred on recycling and incremental supplier adjustments (GE Healthcare, 2024; U.S. DOE, 2022). DC therefore clarifies why Siemens adopts a proactive and transformative approach while GE adapts more incrementally.

5.5.3 OLI Paradigm: Structural Decisions on Ownership, Location, and Internalization

OLI explains how each firm's structural configuration shapes its resilience to REE disruptions (Dunning, 1988). GE Healthcare's ownership advantages lie primarily in recycling technologies and U.S.-based research partnerships, while its production remains geographically concentrated in the United States, reflecting domestic reshoring incentives and security priorities (Oxford Institute for Energy Studies, 2023). Its internalisation efforts focus on magnet recycling rather than upstream material development. Siemens Healthineers expands ownership advantages through sustained R&D in low-REE technologies, distributes production across multiple European sites, and internalises a wider portion of the value chain through refurbishment activities and planned in-house magnet manufacturing (European Commission, 2023; Siemens Healthineers, 2024). These structural differences illustrate how Siemens leverages multi-regional location advantages and deeper internalisation to reduce exposure, while GE's structure remains more nationally anchored.

5.5.4 Institutional Theory: Divergent Contexts Driving Strategic Orientation

Institutional Theory provides the most powerful explanation for why GE and Siemens pursue different resilience pathways. GE Healthcare operates within a U.S. environment that frames REE dependencies through national security, industrial competitiveness, and reshoring imperatives (U.S. DOE, 2024; Herold & Marzantowicz, 2023). These pressures encourage domestic partnerships, recycling-based mitigation, and internal industrial capacity building, rather than broad geographic diversification or eco-design. Siemens Healthineers operates within an EU context shaped by sustainability regulations, circular economy mandates, and strategic autonomy policies (European Commission, 2020; 2023). These frameworks incentivise lifecycle thinking, regionalised production, and material innovation, pushing firms to reconfigure supply chains proactively. As a result, Siemens' strategy reflects regulatory and normative pressures that reward anticipatory and environmentally aligned adaptation.

5.5.5 Synthesis: How the Four Frameworks Interact to Explain Divergence

Taken together, the four frameworks explain the contrasting resilience profiles of GE Healthcare and Siemens Healthineers. RBV establishes that both firms depend on vulnerable VRIN resources. DC clarifies why Siemens senses and responds to structural risk earlier and more comprehensively. OLI shows how Siemens' geographically diversified and technologically integrated structure strengthens its resilience. Institutional Theory reveals why Siemens is encouraged to adopt sustainability-oriented and proactive strategies, while GE operates within a context that favours domestic, security-driven, and reactive approaches. The interaction of these mechanisms explains why Siemens achieves a deeper and more anticipatory resilience strategy, while GE's adaptation remains meaningful but more incremental and shaped by U.S. policy constraints. Taken together, the four theoretical lenses form an integrated causal chain that clarifies why identical shocks do not produce identical strategies. RBV identifies the shared vulnerability; Dynamic Capabilities explain variation in timing and depth of adaptation; Institutional Theory filters which responses are legitimate or incentivised within each political context; and the OLI paradigm translates these pressures into concrete structural choices. It is the interaction of these mechanisms—not any single framework—that ultimately produces the divergent resilience pathways observed in GE Healthcare and Siemens Healthineers.

5.6 Summary

This chapter presented the empirical findings of the study by examining how GE Healthcare and Siemens Healthineers respond to rare earth element (REE) supply disruptions driven by China's dominance in global refining and processing. The analysis demonstrated that both firms face comparable material vulnerabilities due to their dependence on NdFeB magnets, dysprosium stabilisers, and gadolinium compounds used in MRI and CT technologies. However, despite beginning from similar structural exposure, their strategic responses diverge substantially.

GE Healthcare's approach is characterised by reactive adaptation, incremental diversification, and reliance on U.S. industrial policy incentives, with recycling serving as a key mitigation tool. Siemens Healthineers adopts a proactive and institutionally aligned strategy that integrates early supplier diversification, system-wide circularity, and long-term R&D investment in low-REE technologies. These differences are further reinforced by contrasting institutional contexts: U.S. frameworks emphasise national security and reshoring, while EU policies prioritise sustainability, circularity, and strategic autonomy. The comparative analysis showed that Siemens Healthineers demonstrates stronger dynamic capabilities, deeper integration of circularity, more geographically distributed sourcing, and broader internalisation of magnet-related activities. GE Healthcare, while advancing in recycling and domestic partnerships, remains structurally constrained by its reactive posture and narrower diversification base.

The chapter concludes that institutional pressures, dynamic capabilities, and structural supply chain decisions play central roles in shaping firm-level resilience. These findings set the foundation for the concluding chapter, which synthesises theoretical and empirical insights and outlines the implications for international business, policy, and future research.

5.6.1 So What

Overall, the findings show that resilience to rare earth disruptions is shaped not only by technological dependencies but also by how effectively firms align their capabilities, structures, and strategic priorities with the institutional environments in which they operate. Siemens Healthineers achieves more anticipatory and systemic resilience because EU regulatory pressures reward circularity, diversification, and long-term material innovation, whereas GE Healthcare's adaptation remains more incremental and tied to U.S. security-oriented policy incentives. These insights highlight that firm-level responses to geopolitical resource risks are institutionally conditioned rather than purely managerial choices, providing a critical foundation for the analytical and practical implications discussed in Chapter 6.

The comparative findings therefore demonstrate that technological dependency levels do not solely determine resilience, but by how firms' capabilities, supply chain structures, and institutional contexts jointly shape the scope of feasible adaptation. This provides the conceptual bridge into the Discussion chapter.

6. DISCUSSION

6.1 Discussion of Findings

This chapter addresses the central research question of the study: *How do GE Healthcare and Siemens Healthineers respond to the strategic risks of China's dominance in rare earth markets, and what explains the differences in their resilience strategies?* Building on the empirical analysis presented in Chapter 5, the discussion interprets the firms' responses through the integrated theoretical framework developed earlier. The findings show that although both companies face comparable technological dependence on NdFeB magnets, dysprosium stabilisers, and gadolinium compounds—and are therefore exposed to the same geopolitical vulnerabilities—their resilience strategies diverge markedly. Siemens Healthineers adopts a proactive, circularity-oriented, and institutionally aligned approach, whereas GE Healthcare follows a more reactive and domestically anchored adaptation trajectory. This divergence is explained not only by material exposure but also by differences in dynamic capabilities, structural supply chain configurations, and institutional pressures, which together shape the strategic pathways each firm considers feasible and legitimate.

Together, these findings reveal a clear causal mechanism that links external REE shocks to firm-level resilience outcomes. Geopolitical disruptions first create resource vulnerability (RBV), which triggers the mobilisation of dynamic capabilities as firms sense threats, seize mitigation opportunities, and transform aspects of their supply architecture. Institutional contexts then filter and constrain which strategic responses are feasible or incentivised, while OLI structures shape how these responses are translated into location, ownership, and internalisation decisions. This mechanism—shock → vulnerability → capabilities → institutional filtering → structural choice → resilience—explains why GE Healthcare and Siemens Healthineers diverge despite facing the same disruptions.

The comparative analysis reveals a clear causal mechanism that links external geopolitical shocks to firm-level strategic outcomes. Rare earth disruptions—such as China's export quotas and licensing controls—first generate resource vulnerability, as firms lose secure access to VRIN inputs essential for MRI and CT technologies. This triggers the mobilisation of dynamic capabilities, through which firms sense emerging risks, seize available mitigation options, and transform elements of their supply architecture. These adaptive processes are then filtered through institutional contexts, which shape the strategic directions considered legitimate, incentivised, and feasible in each region. The interaction of these stages produces distinct strategic choices, ranging from domestic recycling and incremental diversification (GE Healthcare) to cross-regional supplier dispersion, system-wide circularity, and material innovation (Siemens Healthineers). Over time, these choices culminate in different resilience outcomes, whereby Siemens achieves more anticipatory and structurally embedded resilience, while GE develops more reactive and policy-driven adaptations.

These insights support analytical generalisation rather than statistical generalisation, meaning that the patterns identified in the two cases are used to refine and extend existing international business theory rather than to represent all REE-dependent firms (Yin, 2018).

6.1.1 Strategic Vulnerability and the Centrality of VRIN Resources

The findings affirm that REEs function as VRIN resources for both firms, consistent with the Resource-Based View (Barney, 1991). Neodymium, dysprosium, and gadolinium are indispensable for MRI and CT technologies, underpinning magnetic field strength, thermal stability, and diagnostic precision (Chaban et al., 2024; Hamed et al., 2024). Given that China controls approximately 85–90% of global refining capacity (Guo & Guo, 2024; Schmid, 2019), these inputs are not only technologically strategic but also inherently vulnerable to geopolitical and market shocks.

This concentration explains why events such as the 2010–2011 export quotas and the 2024–2025 export licensing restrictions quickly translated into price spikes, production delays, and heightened uncertainty (Hamed et al., 2024; Depraiter et al., 2025). While both firms rely on the same VRIN inputs, the empirical analysis shows that strategic vulnerability is not experienced uniformly. Siemens Healthineers mitigated exposure earlier through diversification and material innovation, whereas GE Healthcare responded more reactively, intensifying its efforts primarily after disruptions materialised.

Thus, while RBV explains the strategic importance of REEs, it does not fully account for the differences in how firms protect and reconfigure access to these resources. Additional theoretical lenses are required to understand why Siemens achieved more anticipatory resilience compared to GE.

6.1.2 Dynamic Capabilities and the Timing of Adaptation

Dynamic Capabilities Theory offers an important explanation for these divergent trajectories. Siemens Healthineers demonstrates more advanced sensing capabilities, interpreting the 2010–2011 crisis as an indicator of persistent structural risk. This led the company to diversify suppliers, expand circularity initiatives, and invest in lower-REE magnet technologies well before the 2024–2025 restrictions (Siemens Healthineers, 2024). Such proactive behaviour aligns with research showing that firms with strong sensing routines detect weak signals and adapt ahead of environmental shifts (Teece, 2007; Fan & Stevenson, 2018).

GE Healthcare's strategy appears more reactive. Strengthened monitoring, domestic partnerships, and expanded recycling efforts intensified after disruptions had already occurred—first following the 2010–2011 shock and again after China's 2025 export licensing announcement (GE Healthcare, 2025; Investing.com, 2025). This reflects patterns identified in the literature, in which firms with weaker sensing mechanisms rely more on crisis-triggered responses than on anticipatory restructuring (Nakano & Lau, 2019).

Seizing and transforming capabilities further differentiate the two companies. Siemens Healthineers invests in system-level circularity, European magnet manufacturing, and long-term R&D, indicating a structural transformation of its supply architecture. GE Healthcare's initiatives—focused mainly on magnet recycling and incremental diversification—are valuable but narrower in scope (GE Healthcare, 2024). These findings reinforce the role of dynamic capabilities in shaping resilience: proactive sensing, seizing, and transforming enable Siemens to reduce structural exposure, whereas GE's adaptations primarily mitigate short-term risk. This shift moves the comparison beyond a description of firm actions and highlights that the core difference lies in the timing and depth of capability mobilisation.

6.1.3 Structural Supply Chain Configuration Through the OLI Lens

The OLI paradigm helps clarify how each firm's international operations reinforce or reduce exposure to REE risk. Siemens Healthineers leverages location advantages by diversifying across Europe, Australia, and the United States, thereby limiting reliance on any single region (Siemens Healthineers, 2024). Its decision to invest in European magnet manufacturing aligns with EU industrial policy promoting strategic autonomy in critical minerals (Face, 2025; European Commission, 2020). This geographically dispersed configuration strengthens supply chain stability and reduces dependence on Chinese refining. By contrast, GE Healthcare's strategy emphasises U.S.-based capabilities supported by federal reshoring initiatives (U.S. Department of Energy, 2022, 2024). While this domestic focus enhances national security alignment and may facilitate government partnerships, it limits opportunities for broader international diversification. As a result, GE maintains an indirect reliance on Chinese refining capacities (Oxford Institute for Energy Studies, 2023; Hamed et al., 2024).

Patterns of internalisation also differ. Siemens internalises refurbishment, component recovery, and circularity processes, creating greater control over secondary REE flows (Siemens Healthineers, 2024). GE's internalisation is more limited, centred on magnet recycling rather than broader upstream integration (GE Healthcare, 2024). These structural choices influence the depth and durability of resilience mechanisms. This indicates that the divergence between the firms emerges not from specific operational decisions, but from structurally different internationalisation pathways shaped by their respective OLI configurations.

6.1.4 Institutional Pressures as Drivers of Strategic Divergence

Institutional Theory provides one of the strongest explanations for the strategic divergence observed. Siemens Healthineers operates within an EU context shaped by circular economy mandates, environmental standards, and policies promoting strategic autonomy in critical raw materials (European Commission, 2020, 2023). These institutional pressures create incentives for early diversification, recycling integration, and material innovation. As Herold and Marzantowicz (2023) note, institutional complexity pushes European firms toward sustainability-oriented adaptation during supply shocks.

GE Healthcare's institutional environment is fundamentally different. U.S. policy frames REE dependence largely as a national security concern, leading firms to prioritise domestic sourcing, government partnerships, and crisis-responsive measures (U.S. Department of Energy, 2024; CRS, 2023). This contributes to a more reactive strategic profile and limits the adoption of broader circular-system redesigns. These contrasts illustrate how institutions do not merely influence organisational behaviour—they actively shape the strategic pathways that firms consider legitimate and feasible. This shows that institutional environments shape not only firm behaviour but also the feasible strategic menu each firm can pursue under REE constraints.

6.1.5 Synthesising Theoretical Insights

Taken together, the findings show that resilience to REE disruptions emerges from the interaction of resource characteristics, organisational capabilities, supply chain configuration, and institutional pressures. The Resource-Based View (RBV) explains why REEs function as strategic VRIN inputs, creating a shared baseline vulnerability for both GE Healthcare and Siemens Healthineers. However, RBV alone cannot account for the divergent resilience outcomes, which become clear only when the other theoretical lenses are integrated.
Dynamic Capabilities provide this next layer of explanation. Siemens Healthineers demonstrates strong sensing, seizing, and transforming capabilities, enabling early recognition of structural risk and proactive reconfiguration of its supply chain. GE Healthcare, shaped by more reactive sensing routines, adapts primarily once disruptions materialise, leading to incremental rather than transformative change.
These capability differences are further embedded within distinct Ownership–Location–Internalisation (OLI) configurations. Siemens leverages multi-regional location advantages and internalises a broader range of circular and refurbishment activities, thereby reducing exposure to upstream bottlenecks. GE's more domestically concentrated and policy-driven configuration limits the scope of diversification and the depth of internalisation available to it.

Finally, Institutional Theory clarifies why these structural and capability patterns diverge in the first place. EU circular economy and strategic autonomy frameworks incentivise proactive redesign, early supplier dispersion, and life-cycle oriented innovation, whereas U.S. national-security-driven policies emphasise domestic sourcing, crisis-responsive measures, and recycling-based mitigation. As a result, Siemens operates within an institutional environment that rewards anticipatory strategies, while GE adapts within a context that prioritises domestic resilience and reactive adjustment.

In combination, these four theoretical perspectives reveal a coherent mechanism: resource vulnerability triggers capability mobilisation, but the direction and depth of adaptation are ultimately shaped by structural supply chain choices and institutional pressures. This multi-level interaction explains why two firms exposed to the same REE disruptions can arrive at markedly different resilience trajectories.

6.2 Managerial Relevance and Recommendations

The findings of this study offer meaningful managerial insights for firms operating in industries where rare earth elements (REEs) constitute critical technological inputs. As demonstrated in the cases of GE Healthcare and Siemens Healthineers, REE supply disruptions are not temporary anomalies but recurring features of a structurally concentrated and geopolitically sensitive market, in which China maintains significant control over refining capacity (Guo & Guo, 2024; Schmid, 2019). For managers in similarly exposed sectors—such as medical imaging, advanced electronics, and renewable energy—resilience therefore requires strategies that anticipate future shocks rather than merely reacting to external crises. This section discusses the most relevant managerial implications emerging from the comparative analysis.

6.2.1 Strategic Importance of Supply Chain Diversification

A first implication concerns the strategic importance of supply chain diversification. Siemens Healthineers' early geographical dispersion of suppliers across Europe, the United

States, and Australia substantially reduced its exposure to single-country dependencies (Siemens Healthineers, 2024). By contrast, GE Healthcare experienced more pronounced effects from China's 2025 export licensing restrictions due in part to the slower and more domestically centred evolution of its diversification efforts (Investing.com, 2025). These patterns reinforce insights from supply chain risk management literature, which consistently identifies supplier and regional diversification as a central mechanism for mitigating geopolitical and market volatility (Fan & Stevenson, 2018; Nakano & Lau, 2019). For managers, this indicates the importance of strengthening relationships with emerging non-Chinese refining and magnet manufacturing partners while integrating suppliers from jurisdictions aligned with relevant policy frameworks such as the EU's Critical Raw Materials Act (European Commission, 2020). This reinforces that diversification functions not only as supplier management but as a core resilience capability.

6.2.2 Circularity and Lifecycle Strategies for Material Security

A second managerial implication relates to the role of circularity and lifecycle strategies in enhancing resilience. The cases show that recycling, refurbishment, and component recovery can materially reduce dependence on primary REE inputs. Siemens Healthineers' system-wide circular initiatives—ranging from magnet extraction to full-system refurbishment—provide a compelling example of how circularity can simultaneously support environmental objectives and mitigate supply risk (Siemens Healthineers, 2024). GE Healthcare's more targeted magnet recycling initiatives demonstrate that even partial recovery of neodymium and dysprosium can enhance security of supply (GE Healthcare, 2024). Scientific research similarly notes that while recycled REEs cannot yet replace primary supply, they represent a valuable secondary resource stream capable of buffering firms against geopolitical shocks and price volatility (München et al., 2021; Rizos et al., 2022). Managers should therefore view circularity not as a peripheral sustainability initiative but as a core operational capability that contributes directly to supply chain stability.

6.2.3 Innovation and Material Efficiency as Long-Term Resilience Levers

A third insight concerns the significance of innovation and material efficiency as long-term resilience levers. Siemens Healthineers' proactive investment in low-dysprosium magnet R&D and its expansion into European magnet production illustrate how technological innovation can structurally reduce exposure to heavy rare earths (Siemens Healthineers, 2024; Face, 2025). Although stringent medical regulations limit the feasibility of rapid material substitution (Leppälä et al., 2023), incremental advances—such as reduced-dysprosium magnet compositions—can nevertheless strengthen long-term supply security. For managers, this highlights the value of sustained R&D collaboration with universities, public research institutes, and specialised materials laboratories, particularly for technologies in which material efficiency and recyclability are becoming central themes in regulatory frameworks. This highlights that long-term resilience increasingly depends on material efficiency and sustained technological redesign.

6.2.4 Institutional Alignment and Policy-Driven Adaptation

A further managerial implication relates to the need for strategic alignment with institutional environments. The findings demonstrate that Siemens Healthineers' proactive circularity and diversification strategies are strongly shaped by EU policy frameworks that emphasise sustainability, strategic autonomy, and resource efficiency (European Commission, 2020; Herold & Marzantowicz, 2023). GE Healthcare's approach, conversely, reflects U.S. institutional pressures centred on national security, reshoring, and industrial independence (U.S. Department of Energy, 2024). This divergence underscores that institutional contexts not only influence the effectiveness of resilience strategies but also determine which strategic directions are seen as legitimate and supported by policy instruments. For managers, aligning resilience strategies with national or regional institutional priorities can unlock access to regulatory incentives, public funding, and cross-industry partnerships, thereby accelerating organisational adaptation.

6.2.5 Risk Sensing, Scenario Planning, and Organisational Foresight

Finally, the analysis highlights the critical role of advanced risk sensing and scenario planning. Siemens Healthineers' early recognition of structural REE vulnerabilities enabled the firm to redesign its supply chain before new restrictions emerged, whereas GE Healthcare's more reactive adjustments illustrate the challenges associated with relying on crisis-driven responses (GE Healthcare, 2025). This finding aligns with the Dynamic Capabilities framework, which emphasises the link between early warning mechanisms and effective organisational reconfiguration (Teece, 2007). For managers, this suggests the importance of developing dedicated geopolitical intelligence capacities, integrating scenario planning into procurement decisions, and establishing cross-functional processes that ensure risk signals translate into strategic action.

Overall, the managerial relevance of this study lies in demonstrating that resilience to REE supply shocks requires a holistic and forward-looking approach. Firms that combine diversification, circularity, technological innovation, institutional alignment, and strong sensing capabilities are better positioned to manage the structural vulnerabilities of REE-dependent industries. The experiences of GE Healthcare and Siemens Healthineers illustrate that resilience is not achieved through isolated interventions but through the integration of complementary strategies that collectively reduce exposure to external shocks and strengthen long-term competitiveness. For GE Healthcare, the findings suggest prioritising anticipatory sensing capabilities, accelerating supply diversification beyond U.S.-centric pathways, and extending circularity initiatives beyond magnet-level recycling to broader system components. For Siemens Healthineers, sustaining its circularity model and R&D investments is essential, but further risk reduction will require moderating dependence on EU policy incentives by expanding supplier diversification outside Europe. These firm-specific recommendations complement the broader managerial lessons discussed above.

6.2.6 Policy Implications

Beyond firm-level considerations, the findings also carry important implications for policymakers. The divergence between GE Healthcare and Siemens Healthineers illustrates how institutional frameworks shape the feasibility and direction of resilience strategies. Policymakers in both the United States and the European Union can therefore play a decisive role in strengthening industrial preparedness for future REE disruptions. In the U.S., this may involve complementing security-driven reshoring initiatives with stronger incentives for circularity, recycling scale-up, and international collaboration on non-Chinese refining capacity. In the EU, existing circular economy and strategic autonomy policies could be reinforced by targeted support for domestic magnet manufacturing, harmonised recycling standards, and cross-border innovation programmes. More broadly, both regions would benefit from coordinated stockpiling strategies, shared early-warning mechanisms, and transparent data on rare earth supply chains. By aligning industrial policies with the structural vulnerabilities revealed in this study, governments can help reduce systemic exposure and improve long-term resilience across REE-dependent sectors.

6.3 Limitations

Although this study offers a detailed and theoretically grounded analysis of how GE Healthcare and Siemens Healthineers respond to rare earth element (REE) supply disruptions, several limitations must be acknowledged. These limitations do not undermine the validity of the findings but clarify the boundaries within which the conclusions should be interpreted.

6.3.1 Reliance on Secondary Data

A first limitation concerns the study's exclusive reliance on secondary data. Document analysis enables triangulation across scientific literature, corporate reports, policy documents, and industry analyses, thereby providing a broad and historically informed perspective (Bowen, 2009). However, secondary sources inevitably reflect public-facing narratives that may omit internal organisational dynamics, informal decision-making processes, or confidential supply chain arrangements. As Yin (2018) notes, secondary data can support strong analytical generalisation, yet it cannot fully substitute for primary evidence such as interviews, internal documents, or direct observation. As a result, the analysis may not capture the full complexity of managerial reasoning behind specific strategic choices, particularly in the context of high-stakes geopolitical uncertainty.

6.3.2 Narrow Empirical Scope

A second limitation relates to the narrow empirical scope of the study. The comparison focuses on two multinational firms within the medical imaging sector, selected because they face similar technological dependencies on REEs while operating under distinct institutional environments. Although this comparative approach enhances analytical insight, it limits the breadth of generalisation. As emphasised by Eisenhardt (1989), case study research prioritises depth over scope, enabling theoretical rather than statistical generalisation. Firms in adjacent industries—such as renewable energy, consumer electronics, or automotive manufacturing—may exhibit different patterns of adaptation due to differing regulatory constraints, supply chain architectures, or technological requirements.

6.3.3 Opacity of Global Rare Earth Supply Chains

A third limitation concerns the inherent opacity of global REE supply chains. The rare earth sector is characterised by fragmented data availability, geopolitical sensitivity, and limited transparency in refining and separation activities, much of which are concentrated in China (Mancheri, 2015; Guo & Guo, 2024). Consequently, any analysis of firm-level exposure or diversification must contend with incomplete or non-public information regarding upstream refining pathways, supplier relationships, and magnet alloy compositions. This structural opacity introduces an unavoidable degree of uncertainty into the interpretation of supply chain risks and resilience strategies.

6.3.4 Temporal Boundaries of the Analysis

A further limitation involves the temporal boundaries of the study. The analysis encompasses firm responses across two major disruption periods—the 2010–2011 export quotas and the 2024–2025 export licensing controls (Depraiter et al., 2025). However, some of the strategic initiatives identified—such as Siemens Healthineers' European magnet production facility or GE Healthcare's evolving recycling programmes—are ongoing and have not yet produced full operational outcomes. As Miles and Huberman (1994) argue, qualitative analysis often captures processes in motion, and the long-term impacts of these strategic decisions may only become visible over a more extended timeframe. Future policy developments in both the EU and the United States may also reshape institutional incentives and alter the strategic landscape (European Commission, 2020; U.S. Department of Energy, 2024).

6.3.5 Sector-Specific Technological and Regulatory Constraints

Finally, the technological and regulatory specificity of the medical imaging sector constitutes an important limitation. MRI and CT systems require exceptionally high-purity REEs and must comply with stringent regulatory frameworks such as the EU Medical Device Regulation and U.S. FDA requirements (Leppälä et al., 2023; Chaban et al., 2024). These constraints reduce the feasibility of rapid material substitution or design modifications. Consequently, some resilience strategies identified in this study—particularly circularity initiatives and incremental material innovations—may not be directly transferable to industries with lower performance requirements or more flexible regulatory environments. Despite these limitations, the study provides a robust empirical and theoretical contribution by demonstrating how resource characteristics, dynamic capabilities, supply chain configurations, and institutional pressures jointly shape firm resilience to REE disruptions. Acknowledging these boundaries highlights opportunities for future research, including primary-data collection through interviews, expansion to additional case firms, and longitudinal studies examining how emerging policy interventions influence resilience over time.

6.4 Theoretical Contributions

6.4.1 Contributions to the Resource-Based View

This study offers several contributions to international business (IB) theory by integrating geopolitical risk, critical material dependencies, and firm-level adaptation into a unified analytical perspective. First, the findings extend the Resource-Based View by demonstrating how VRIN resources such as rare earth elements (REEs) generate not only strategic advantage but also strategic vulnerability when global supply is concentrated in a single political actor. While RBV typically emphasises firm heterogeneity and inimitability, this study shows that firms may share identical VRIN dependencies yet experience different resilience outcomes depending on their capability configurations and institutional environments. In this sense, the research highlights the limitations of RBV when confronted with systemic geopolitical constraints and proposes a more dynamic interpretation of resource vulnerability in globally concentrated markets.

6.4.2 Contributions to Dynamic Capabilities Theory

Second, the study advances Dynamic Capabilities (DC) theory by illuminating how sensing, seizing, and transforming capabilities operate under conditions of geopolitical uncertainty. The comparative analysis between GE Healthcare and Siemens Healthineers shows that proactive sensing and transformative investment—not merely operational flexibility—play a decisive role in shaping resilience to politically induced supply shocks. While prior DC literature emphasises turbulence and technological change, the empirical findings demonstrate how geopolitical shocks trigger capability mobilisation and reveal substantial variations in firms' ability to anticipate and structurally reconfigure their supply chains. This extends DC theory into the domain of critical material risk and contributes to emerging debates on how firms adapt to exogenous disruptions beyond traditional market or technological volatility (Teece, 2007; Fan & Stevenson, 2018).

6.4.3 Contributions to the OLI Paradigm

Third, the study enriches the OLI paradigm by linking ownership, location, and internalisation decisions directly to resource security considerations. Existing OLI literature typically focuses on efficiency, transaction costs, and competitive advantage. By contrast, this research shows that in industries dependent on critical minerals, OLI choices become instruments of geopolitical risk mitigation. Siemens Healthineers' diversification across European and Asia-Pacific suppliers, combined with its internalisation of refurbishment and magnet-related processes, illustrates how multinational enterprises deploy OLI strategies to reduce exposure to concentrated upstream bottlenecks. GE Healthcare's more domestically anchored configuration further demonstrates how institutional incentives shape the boundaries of feasible OLI options. Thus, the study adds a critical mineral and geopolitical dimension to the OLI framework, expanding its explanatory power in contexts characterised by global supply insecurity.

6.4.4 Contributions to Institutional Theory

Fourth, the research makes a substantive contribution to Institutional Theory by highlighting how national and supranational regulatory environments act as filters that shape strategic adaptation. While institutional literature often emphasises isomorphism and legitimacy pressures (DiMaggio & Powell, 1983), this study shows that institutions can generate strategic divergence rather than convergence. EU circular economy mandates incentivised Siemens Healthineers to pursue lifecycle extension, early diversification, and material innovation, while U.S. security-driven critical minerals policy channelled GE Healthcare toward domestic partnerships, recycling programmes, and incremental diversification. The findings therefore demonstrate that institutional contexts do not simply constrain firms—they actively direct the trajectory, speed, and depth of resilience strategies under geopolitical disruption.

6.4.5 Contributions to Theoretical Integration in IB

Finally, by integrating RBV, Dynamic Capabilities, OLI, and Institutional Theory into a single analytical model, the study contributes to theoretical synthesis within IB research. Critical material disruptions reveal the limitations of treating these frameworks separately. The interaction between resource vulnerability, adaptive capabilities, international structural decisions, and institutional filtering generates a multi-level explanatory mechanism that cannot be captured by any single theory alone. The conceptual integration developed in this thesis therefore offers a more holistic understanding of how multinational firms navigate geopolitical shocks in strategically constrained resource environments, providing a foundation for future research on firm adaptation in politically sensitive global value chains.

6.5 Future Research Directions

This study points to several avenues for future research. First, the exclusive use of secondary data suggests the value of incorporating primary evidence, such as interviews with procurement managers, engineers, or policy specialists, to capture internal decision-making processes that public documents cannot reveal. Second, future studies could expand the comparative scope by examining additional firms or industries reliant on rare earths—such as renewable energy, electric vehicles, or consumer electronics—to test whether the mechanisms identified here hold across different technological and regulatory contexts. Third, given that several strategic initiatives observed in this study (e.g., Siemens' European magnet facility) are ongoing, longitudinal research could assess how these measures affect resilience over time. Finally, further work could deepen the integration of IB theory with geopolitical risk research, exploring how dynamic capabilities and institutional pressures interact under other forms of strategic dependency, such as semiconductors or pharmaceutical inputs.

7. CONCLUSION

This thesis set out to answer the research question: How do GE Healthcare and Siemens Healthineers respond to the strategic risks of China's dominance in rare earth markets, and what explains the differences in their resilience strategies? By integrating insights from international business theory with an empirically grounded comparative case study, the analysis demonstrates that both firms face structurally similar vulnerabilities linked to their dependence on neodymium, dysprosium, and gadolinium—resources that function as VRIN inputs in MRI and CT production. However, despite these shared constraints, GE Healthcare and Siemens Healthineers pursue markedly different resilience pathways shaped by their dynamic capabilities, internationalisation choices, and institutional environments.

The empirical findings show that GE Healthcare's strategy is predominantly reactive, becoming more robust in response to discrete external shocks such as the 2010–2011 export quotas or China's 2025 licensing controls. Its approach centres on domestic partnerships, magnet recycling, and incremental supplier diversification. These measures reduce immediate exposure but only partially address the structural roots of REE dependency. By contrast, Siemens Healthineers adopts a proactive and system-oriented strategy, characterised by early supplier diversification, deep integration of circularity practices across the product lifecycle, and long-term investment in low-REE magnet R&D and European magnet production. These differences reflect not only stronger sensing and transforming capabilities but also an institutional environment—shaped by EU circular economy and strategic autonomy policies—that actively rewards anticipatory adaptation.

The comparative evidence contributes to international business theory in several ways. First, it extends the Resource-Based View by demonstrating that strategic value and strategic vulnerability can coexist when VRIN inputs are globally concentrated and politically weaponised. Second, it shows how dynamic capabilities determine whether firms interpret disruptions as temporary shocks or as signals of long-term structural dependency requiring transformation. Third, it enriches the OLI paradigm by illustrating how ownership, location, and internalisation decisions can function as tools of geopolitical risk mitigation. Finally, it demonstrates the importance of institutional contexts in shaping not only the options available to firms but also the directions of strategic change deemed legitimate and incentivised.

From a managerial perspective, the thesis highlights that resilience to critical material disruptions requires an integrated approach combining diversification, circularity, innovation, and institutional alignment. For policymakers, the analysis underscores that institutional frameworks—whether U.S. security-led or EU sustainability-driven—directly influence corporate strategic behaviour and can either enable or constrain forward-looking adaptation. Several limitations must be acknowledged. The reliance on secondary data means some internal organisational processes remain outside the scope of this study, and the focus on two firms within a single sector limits the breadth of empirical generalisation. Furthermore, rare earth supply chains remain partially opaque, and several strategic initiatives—such as Siemens' European magnet facility—are ongoing and may evolve in ways this study cannot yet observe. Nevertheless, the findings allow for analytical generalisation: the theoretical mechanisms identified here can inform the study of other firms and industries facing geopolitically concentrated critical materials.

In sum, this thesis demonstrates that firm resilience to rare earth supply shocks is not determined solely by material dependence, but by the interaction of organisational capabilities, structural supply chain choices, and institutional pressures. Siemens Healthineers achieves more anticipatory and structurally embedded resilience because its strategy is shaped by an institutional context that prioritises sustainability, circularity, and strategic autonomy. GE Healthcare, by contrast, adapts within a U.S. environment that frames REE risk primarily as a national security issue, resulting in more reactive and domestically anchored responses. These findings contribute to a deeper understanding of how multinational enterprises navigate geopolitical resource risks and highlight the need for integrated theoretical approaches to explain firm behaviour in politically sensitive global value chains.

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