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EUROPE'S MATERIALS SECURITY DILEMMA: CRITICAL RAW MATERIALS, STRATEGIC DEPENDENCY, AND THE EU'S RESPONSE

Tesi di Laurea in Geography of Conflict

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To my father,

who did not live to see the completion of this journey.

Although you are no longer here to witness this achievement, your memory has accompanied me through every challenge, every setback, and every success.

I dedicate this thesis to your memory with gratitude, respect, and love.

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Abstract

La transizione globale verso un sistema energetico a basse emissioni di carbonio sta modificando le condizioni strutturali della sicurezza energetica internazionale, in particolare per l'Unione Europea. Dopo decenni in cui le strategie economiche e di sicurezza sono state plasmate dalla dipendenza dai combustibili fossili importati, il passaggio alle energie rinnovabili introduce nuove vulnerabilità legate all'approvvigionamento. Questa trasformazione comporta quello che la presente tesi definisce come il "paradosso materiale": se da un lato le fonti rinnovabili riducono l'esposizione alla volatilità dei mercati globali del petrolio e del gas, dall'altro le infrastrutture necessarie per produrre e immagazzinare tale energia dipendono fortemente dalle materie prime critiche. Questi minerali presentano livelli di concentrazione geografica e industriale spesso superiori a quelli dei combustibili fossili tradizionali. L'obiettivo della ricerca è analizzare come questa evoluzione stia spostando la dipendenza strategica europea dai combustibili alle materie prime industriali, evidenziando i rischi politici, le vulnerabilità delle catene di approvvigionamento e le risposte adottate a livello politico.

Per analizzare tali dinamiche, la tesi integra la geopolitica classica delle risorse, la letteratura sulla maledizione delle risorse e le teorie dell'interdipendenza strumentalizzata (*weaponized interdependence*). Uno dei principali contributi concettuali dello studio è il "dilemma della sicurezza delle materie prime". Questo modello spiega come gli sforzi degli Stati dipendenti dalle importazioni per assicurarsi l'accesso ai minerali critici possano aumentare la competizione geopolitica e l'incertezza nelle catene di approvvigionamento globali, anche in assenza di conflitti aperti. Le politiche di diversificazione delle forniture, di controllo degli investimenti e di sostegno industriale, pur finalizzate a rafforzare la resilienza economica, possono infatti trasformare reti commerciali costruite per l'efficienza economica in potenziali strumenti di pressione politica. Ne deriva la necessità, per gli attori dipendenti dalle importazioni, di bilanciare i benefici dell'integrazione nei mercati globali con i rischi associati a una forte esposizione alle interruzioni delle forniture.

Dal punto di vista metodologico, lo studio adotta un approccio qualitativo basato sull'analisi comparata di casi studio. Le materie prime critiche vengono esaminate in base

alle caratteristiche specifiche delle rispettive catene di approvvigionamento, anziché essere considerate come una categoria uniforme. La selezione dei materiali si basa su una precedente ricerca quantitativa condotta su venti Paesi extraeuropei, dalla quale emerge che l'abbondanza geologica è spesso associata a fragilità istituzionali, minacce alla sicurezza e sviluppo disomogeneo. Sulla base di tali evidenze, la tesi si concentra su cobalto, litio ed elementi delle terre rare. Il confronto dimostra che l'Unione Europea non affronta una sola forma di dipendenza, ma vulnerabilità differenti, legate a diverse fasi delle catene globali del valore.

L'analisi della filiera del cobalto evidenzia una dinamica definita come "nexus di instabilità". L'estrazione del cobalto è fortemente concentrata nella Repubblica Democratica del Congo, che rappresenta circa il settanta per cento della produzione mondiale, mentre gran parte del materiale viene successivamente raffinata in Cina. La vulnerabilità europea deriva dall'interazione tra questa concentrazione geografica e la fragilità istituzionale del principale Paese produttore. Il caso congolese conferma molte delle dinamiche individuate dalla letteratura sulla maledizione delle risorse, mostrando come la dipendenza dai minerali in contesti caratterizzati da istituzioni deboli sia associata a problemi di sicurezza interna, corruzione e condizioni di lavoro problematiche. Inoltre, poiché il cobalto viene estratto prevalentemente come sottoprodotto del rame e del nichel, la sua offerta risulta relativamente rigida, limitando la capacità di risposta del mercato ed esponendo il settore europeo delle batterie a una significativa volatilità dei prezzi.

Il caso del litio presenta una vulnerabilità differente, definita nella tesi come il "paradosso del midstream". A differenza del cobalto, le riserve e le attività estrattive di litio sono distribuite tra Paesi relativamente stabili, come Australia, Cile e Argentina. Tuttavia, la sicurezza dell'approvvigionamento europeo rimane limitata perché il materiale estratto deve essere sottoposto a complessi processi di trasformazione chimica prima di poter essere utilizzato nella produzione di batterie. Questa fase intermedia della filiera è ampiamente controllata dalla Cina, che detiene una quota dominante della capacità globale di lavorazione. Di conseguenza, la diversificazione geografica dell'estrazione viene compensata dalla concentrazione nella fase di raffinazione. Il caso dimostra che la sola diversificazione delle fonti di approvvigionamento non è sufficiente a garantire l'autonomia strategica quando il principale collo di bottiglia si trova nella fase di trasformazione industriale.

Gli elementi delle terre rare rappresentano la forma più estesa di dipendenza analizzata nella ricerca e vengono classificati come un vero e proprio "collo di bottiglia industriale". In questo settore, la dipendenza europea dalla Cina interessa quasi l'intera catena del valore, dall'estrazione alla produzione dei magneti permanenti utilizzati nelle turbine eoliche e nei veicoli elettrici. Questa posizione dominante è il risultato di politiche industriali di lungo periodo orientate all'integrazione verticale e al controllo tecnologico. La capacità di influenza derivante da tale concentrazione è stata dimostrata sia attraverso dispute geopolitiche sia mediante restrizioni alle esportazioni. Ridurre questa dipendenza richiederà all'Unione Europea di ricostruire capacità industriali e tecnologiche oggi concentrate all'estero.

La tesi esamina inoltre la risposta dell'Unione Europea, evidenziando il passaggio da una forte fiducia nei mercati globali a una strategia di "autonomia strategica aperta". Lo strumento centrale di questo approccio è il *Critical Raw Materials Act* (CRMA), che mira a rafforzare la resilienza europea attraverso l'aumento dell'estrazione, della lavorazione e del riciclo all'interno dell'Unione, riducendo al tempo stesso la dipendenza da singoli fornitori esterni. A tal fine, il regolamento introduce progetti strategici, procedure autorizzative accelerate, meccanismi di acquisto congiunto e obblighi di valutazione dei rischi lungo le catene di approvvigionamento.

Nonostante la sua rilevanza, il CRMA presenta diversi limiti strutturali. Rispetto agli Stati Uniti e alla Cina, il modello europeo resta finanziariamente frammentato e dipende in larga misura da strumenti di finanziamento già esistenti. Gli elevati costi energetici e operativi continuano inoltre a scoraggiare gli investimenti nella capacità europea di raffinazione. Parallelamente, l'espansione delle attività minerarie incontra spesso ostacoli legati alla tutela ambientale e all'opposizione delle comunità locali. Sebbene il riciclo rappresenti una priorità strategica, i tempi necessari per sviluppare infrastrutture adeguate ne limitano il contributo nel breve periodo.

La tesi conclude analizzando i possibili scenari per l'Unione Europea tra il 2030 e il 2050. I risultati mostrano che la decarbonizzazione non elimina i vincoli geopolitici, ma li trasferisce su nuove basi industriali e materiali. L'autosufficienza mineraria completa appare un obiettivo difficilmente raggiungibile. La posizione strategica europea dipenderà piuttosto dalla capacità di gestire efficacemente le relazioni di interdipendenza, riducendo l'esposizione a coercizioni geopolitiche e shock delle forniture attraverso la diversificazione delle fonti, investimenti mirati nella lavorazione e nel riciclo e il rafforzamento delle capacità industriali interne. Allo stesso tempo, i decisori politici dovranno conciliare le esigenze dello sviluppo industriale con gli obiettivi ambientali, colmando il divario tra le ambizioni della transizione energetica e le realtà delle catene di approvvigionamento globali.

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Abbreviations

1. **CDAs**: Community Development Agreements
2. **CEPS**: Centre for European Policy Studies
3. **CRMA**: Critical Raw Materials Act
4. **CRMs**: Critical Raw Materials
5. **DPA**: Defense Production Act
6. **DRC**: Democratic Republic of Congo
7. **ECB**: European Central Bank
8. **EIA**: Environmental Impact Assessment
9. **EIB**: European Investment Bank
10. **EPRS**: European Parliamentary Research Service
11. **ESG**: Environmental, Social, and Governance
12. **EU**: European Union
13. **EV**: Electric Vehicle
14. **GDP**: Gross Domestic Product
15. **HD**: Habitats Directive
16. **IEA**: International Energy Agency
17. **IRA**: Inflation Reduction Act
18. **IRENA**: International Renewable Energy Agency
19. **JOGMEC**: Japan Organization for Metals and Energy Security
20. **JRC**: Joint Research Centre
21. **LIB**: Lithium-ion battery
22. **METI**: Ministry of Economy, Trade and Industry

23. **MoUs**: Memorandums of Understanding
24. **NdFeB**: Neodymium-iron-boron
25. **NIMBY**: Not In My Backyard
26. **ODA**: Overseas Development Assistance
27. **OECD**: Organization for Economic Co-operation and Development
28. **OSA**: Open strategic autonomy
29. **R&D**: Research and development
30. **REEs**: Rare Earth Elements
31. **RoW**: Rest of world
32. **SLO**: Social Licence to Operate
33. **SQM**: Refers to a major Chilean lithium producer
34. **SRMs**: Strategic Raw Materials
35. **UNESCO**: the United Nations Educational, Scientific and Cultural Organization
36. **USGS**: U.S. Geological Survey
37. **WFD**: Water Framework Directive
38. **WTO**: World Trade Organization
39. **ASM**: Artisanal and Small-Scale Mining
40. **CSDDD**: The Corporate Sustainability Due Diligence Directive

Chapter I – Introduction

For over half a century, a single question has determined Europe's energy security: how to ensure access to fossil fuels. Europe’s economic models, foreign policy, and security strategies have been heavily influenced by dependence on external energy sources—Russia’s gas and the Middle East’s oil. This has produced significant security risks, which became acutely visible in the 2022 energy crisis[1]. For many years, the conventional wisdom was that energy insecurity in Europe was caused by fuel dependency.

Energy security today is no longer defined only in terms of oil and gas. The global shift toward renewable energy, pushed by environmental imperatives, technological advances, and geopolitics, is changing the foundations of energy security. Solar panels and wind farms are now at the center of the energy security debate in Europe. Unlike oil and gas, which are not sustainable in the long term, solar and wind energy do not rely on fossil fuels. However, they do rely on something else: critical raw materials (CRMs) such as lithium, cobalt, and rare earth elements (REEs). Without critical materials, Europe cannot produce the technologies needed to achieve energy security.

This represents a “material paradox,” in which energy security is provided by renewable energy sources such as wind and sun but the technologies needed to harness these energy sources rely on critical materials that are highly concentrated in a few countries. In this sense, Europe is shifting from dependence on fossil fuels to dependence on critical materials.

This change leads to what can be described as a “materials security dilemma”, a concept developed in this thesis to explain how efforts to secure access to critical raw materials may unintentionally intensify geopolitical competition. Europe cannot completely break dependence, as interdependence is a feature of globalized supply chains. The challenge is therefore not to achieve full self-sufficiency but to manage these new

[1] This refers to the severe energy shortages and price shocks in Europe triggered by the Russian invasion of Ukraine in February 2022, which resulted in the drastic reduction of Russian natural gas exports to the European Union.

interdependencies so that excessive vulnerability to coercion, disruption, or political pressure does not emerge.

These issues are not abstract. Global supply chains for critical minerals already show patterns that mirror, and in some cases exceed, Europe's previous vulnerabilities. Lithium processing is concentrated in a few countries; cobalt production is largely centered in the Democratic Republic of Congo; and China dominates the supply chain for rare earth minerals. These materials also have strategic uses. In 2010, China halted rare earth exports to Japan during a political dispute, demonstrating how critical materials can be used strategically. [2]

As major countries adjust to this new reality, new policy initiatives are emerging. The European Union has introduced the Critical Raw Materials Act (CRMA), while the United States is pursuing its own approach through the Inflation Reduction Act (IRA).[3] At the same time, China continues to expand its global supply chain for these minerals. Japan is also an important reference case because it experienced supply disruptions during the rare earth dispute with China and later developed a long-term strategy to strengthen supply chain security.

This thesis builds on insights from a previous research project conducted in 2025 that analyzed 20 non-European countries and revealed the extreme concentration of lithium, cobalt, and rare earth elements. That research showed that Europe's future vulnerabilities are not only economic but also political and security-related. This thesis extends that research by examining how each of these materials creates different forms of dependency and what this means for the long-term energy security of Europe.

To examine these dynamics, the thesis adopts a qualitative, comparative case study approach on lithium, cobalt, and rare earth elements. This methodological choice reflects the argument that the geopolitical implications of critical raw materials cannot be understood only through quantitative measures of supply and demand, but must also

[2] This embargo followed a diplomatic dispute over the Senkaku/Diaoyu Islands, which escalated after the Japanese Coast Guard detained a Chinese fishing captain. The event and its implications for resource weaponization are discussed in detail in Chapter 2.

[3] The U.S. Inflation Reduction Act (IRA), adopted in 2022, marked a major shift in U.S. industrial policy by providing substantial subsidies and financial incentives to support domestic clean energy industries and strengthen critical raw material supply chains among trusted partners.

include political, institutional, and structural factors that shape global supply chains. The selection of these materials builds directly on the empirical patterns identified in the earlier comparative dataset, which highlighted both their high degree of supply concentration and their strategic importance for green and digital technologies. Rather than treating critical raw materials as a homogeneous category, the analysis focuses on how each material generates a different form of dependency. Cobalt represents a case of extreme concentration linked to broader structural fragility in supplier countries such as the Democratic Republic of the Congo (USGS, 2024; Institute for Economics & Peace, 2024), lithium is associated with reserve concentration combined with midstream processing bottlenecks (USGS, 2024), and rare earth elements illustrate a model of dependency driven by industrial and structural dominance, particularly in China (IEA, 2021). By comparing these three cases, the thesis aims to move beyond a generalized understanding of resource dependency and instead analyze how different configurations of supply chains generate different geopolitical risks for the European Union.

1. Research Aim and Objectives

This thesis aims to analyze how the global transition from fossil fuel–based energy systems to mineral-intensive renewable energy systems reshapes patterns of geopolitical dependency, with a particular focus on the European Union. It develops the concept of the materials security dilemma to explain how efforts by import-dependent actors to secure access to critical raw materials may unintentionally intensify competition, fragmentation, and strategic vulnerability within global supply chains.

Building on both existing literature and original empirical research, the thesis seeks to move beyond traditional understandings of resource dependency by examining how vulnerability emerges not only from resource scarcity, but from supply chain concentration, governance conditions in supplier countries, and the location of industrial and technological chokepoints.

To achieve this aim, the thesis pursues the following objectives:

1. **To conceptualize the transformation of energy geopolitics** from a fossil fuel–based system to a mineral-intensive system, and to explain how this shift produces the “material paradox” at the core of the energy transition.
2. **To develop a theoretical framework** that connects classical resource geopolitics, resource curse literature, and contemporary debates on critical raw materials, in

order to explain how new forms of dependency and vulnerability emerge in the context of decarbonization.

3. **To identify and compare different mechanisms of strategic dependency** associated with lithium, cobalt, and rare earth elements, based on their distinct patterns of concentration, governance context, and industrial structure.
4. **To assess how these material-specific dependencies translate into geopolitical risks for the European Union**, particularly in terms of exposure to supply disruption, coercion, and structural vulnerability within global supply chains.
5. **To evaluate the role of resilience and strategic autonomy** as policy responses, examining how diversification, industrial policy, and supply chain restructuring can mitigate vulnerability without eliminating interdependence.

2. Theoretical Framework: From the Resource Curse to the Materials Security Dilemma

This chapter aims to establish an analytical foundation to understand the evolving dependency of Europe on critical raw materials in the context of the green transition. The shift from an energy system based on fossil fuels to an energy system based on mineral-intensive technologies has shaped the strategic landscape and created a new form of vulnerability, dependency, and potential coercion. Moving away from fossil fuels (decarbonization) does not eliminate geopolitical competition, but it shifts the states' struggles around new materials, industrial bottlenecks, and supply chain concentration.

Existing literature has extensively examined resource dependency through the lenses of resource conflict, the resource curse, and energy transition studies. However, less attention has been given to how the shift toward mineral-intensive energy systems reshapes dependency into questions of resilience, adaptation, and strategic vulnerability within global supply chains. This gap is particularly relevant for Europe, where the energy transition creates new forms of exposure rooted not in fuel access but in industrial and material concentration. This thesis addresses this gap by developing a framework that connects resource geopolitics, transition economics, and strategic autonomy.

The conceptual framework of this chapter is based on the previous empirical research conducted by the author on mineral reserves, mineral concentration, and governance indicators of a group of 20 non-European countries. The dataset showed that even countries rich in resources can have a constant pattern of supply asymmetry, institutional fragility, and uneven development outcomes. Data from several countries show that high mineral endowment was linked to weak governance indicators, fragility to security threats, and environmental vulnerability. The findings do not necessarily claim that resource-rich countries always have weak institutions and instability; instead, they highlight a consistent tension between material abundance and structural resilience. While it is not an established theory in this thesis, it showed governance fragility and structural vulnerability related to a high level of concentration in raw materials. This insight becomes directly relevant for understanding Europe's emerging vulnerabilities, as it shows similar dynamics in vulnerability on a global scale.

In order to conceptualize this transformation, the theoretical framework is structured around three interconnected sections. The first explores the classical geopolitics of resource scarcity, including the paradigms of resource wars and the Resource Curse. The second examines the transformation of the global energy system and introduces the concept of the material paradox, supported by economic perspectives on resource constraints and transition dynamics. The third analyzes the contemporary geopolitics of critical raw materials, including the risks of resource weaponization and the growing emphasis on resilience and strategic autonomy. Taken together, these sections demonstrate the shift from a fossil-fuel geopolitical order focused on territorial control and energy flows toward a new form of vulnerability rooted in industrial concentration and material dependence.

2.1 Old Geopolitics: Resources, Power, and Political Fragility

The study of international relations in the 20th century was highly linked to natural resources as an important element of power. Energy—especially oil—was not considered just a commodity in the global market, but it was a strategic and important base for military strength, industrial development, and national autonomy. A relatively straightforward assumption was that having control over resources helps with geopolitical power, while vulnerability to supply disruption leads to strategic risk. This perspective, which was then described as a "resource war" framework (Klare 2001),[4] did not claim that the conflict is inevitable in any similar situation; instead, it argued that competition over scarcity and the materials that are strategically important leads to rivalry and tension in the international system.

However, over time, scholars began questioning whether resources themselves were the main drivers of conflict. Philippe Le Billon (2001) shifted the attention away from material existence toward political structure by offering a more refined interpretation: natural resources do not necessarily cause violence, but they do shape the incentives, funding mechanisms, and territorial strategies of actors in particular institutional settings. After the Cold War, the ideological sponsorship began to decline, and several armed groups (mostly rebels) relied on revenues coming from oil, diamonds, and timber to finance their military campaigns. In these cases, resources have become a key funding source for war economies. Notably, conflicts do not emerge only because resources exist; they emerge because of the way the actors control, distribute, and monetize them. According to Le Billon, physical characteristics of commodities matter too. The resources that are easily extractable and transportable can empower non-state actors, while the resources concentrated geographically and considered "infrastructure-intensive" are more a tool to reinforce the centralized control. Making these distinctions between different types of materials is important, as it helps determine whether a conflict emerges as secession, rebellion, or competition for control of the state.

Shannon O'Lear (2004), in her study of the Caspian region, similarly criticizes deterministic interpretations of the relationship between natural resources and conflict. Her study demonstrates that resource development, in some cases, accelerates geopolitical tensions, but in other contexts, it encourages negotiation, bilateral agreements, infrastructure cooperation (e.g., *commercial contracts and pipeline arrangements*), and even institutional coordination. The presence of energy resources alone does not predict a single outcome. Other elements, such as political context, regional power dynamics, legal status, boundary demarcation, and institutional

[4] Klare's (2001) analysis focused mainly on competition over physical access to scarce resources, particularly oil and water, and the potential for territorial disputes and military conflict. This differs from the contemporary focus on industrial dependencies, supply-chain vulnerabilities, and the use of economic networks as tools of coercion.

arrangements, influence whether resource wealth becomes a source of conflict or collaboration. Overall, her study complicates the simple narrative “resources cause war” and frames resources as factors that influence incentives within a specific political context.

The primary focus of these debates was on interstate rivalry and conflict financing, while another group of scholars considered the domestic dimension of resource wealth and examined how resources affect political and economic growth. This debate later became known as the Resource Curse, explaining the paradox of how resource-rich countries experience slower economic growth compared to resource-poor ones. Sachs and Warner (1995) conducted one of the first systematic cross-country empirical investigations. Their data for the period 1970-1989 shows that countries with a high ratio of primary-product exports to GDP in 1970 generally experience slower economic growth in subsequent decades. The findings suggested that a high level of dependence on primary-product exports is likely linked to weaker long-term growth performance. In this sense, natural resources were not simply a source of revenue, but a structural factor influencing broader patterns of economic performance.

Subsequent research tried to explain the mechanisms behind these patterns. One central explanation is linked to governance and accountability. Ross (2012) argues that governments rely on oil rather than taxation; they do not feel bottom-up pressure for transparency and citizen responsiveness, giving rulers greater autonomy from society. In other words, if a state does not depend on its citizens for revenue, the traditional link between taxation and political representation becomes weaker. This dynamic over time can strengthen patronage networks, make the institutional oversight weak, concentrate the executive power in the hands of a small group, and as a result, increase the risk of conflict. Collier and Hoeffler (2004) argue that countries with an economy that relies heavily on commodity exports are more likely to escalate a civil war, especially when the institutional capacity is low. Auty (2004) similarly emphasizes that a combination of resource wealth and weak governance structure can foster distributive competition and increase the possibility of civil strife. In this point of view, the problem is not about resource abundance itself but more about how the revenues are distributed and how institutions are managed.

The empirical patterns of earlier research are strongly aligned with these theoretical claims. Many states rich in mineral wealth were examined in the dataset; the outcome shows that high levels of resource concentration do not have a direct correlation with human development or institutional strength. Instead, material abundance is frequently linked with governance fragility, vulnerable to security threats and environmental stress. In the meantime, there are variations across cases that confirm Rosser's (2006) critique on deterministic conclusions, as he argues, "Most of the perspectives are highly deterministic," and there is "considerable variation in the development outcomes experienced by individual resource-abundant countries." Therefore, the dataset supports a central insight of the Resource Curse literature: resources are likely to create structural risks, but the quality of political institutions determines whether those risks lead to fragility.

These debates draw the conceptual baseline of this thesis. The classical literature argues that resources are important for power, governance, and security, at the same time showing it is "institutions" that determine whether they have positive or negative effects. However, a number of these scholars focused mainly on fossil fuels and traditional extractive industries (e.g., coal, gas). Since the global energy system shifts towards renewable technologies that rely on critical raw materials, the important question is whether this transition is going to re-emerge in a new form of concentration, leading to dependency and vulnerability.

2.2 The New Problem: The Material Paradox of Energy Transition

2.2.1. From a Fuel-Intensive to a Material-Intensive Energy System

The global energy transition is not only about a shift in technology (e.g., solar panels, wind turbines); it also includes the materials from which the energy systems are physically built. Under the fossil-fuel model, energy security relied heavily on the continuous extraction and transport of oil and gas; renewable energy systems, on the other hand, require little fuel during operation but depend on large quantities of minerals during manufacturing. According to the International Energy Agency (IEA 2021), clean energy technologies need more minerals (i.e., they are more mineral-intensive) than conventional systems. For instance, an electric vehicle requires mineral inputs almost six times more than a conventional car, and an onshore wind plant requires mineral inputs around nine times more than a comparable gas-fired plant. As there was a rapid increase in renewable deployment between 2010 and 2020, the mineral intensity increased accordingly to support new power generation capacity—demonstrating a structural shift toward mineral-intensive technologies that require a large quantity of materials and are primarily built onto a long-lasting infrastructure. This shift can also be seen in the way energy systems are organized. Unlike fossil fuels, which can be stored easily and transported across global markets, renewable electricity systems rely more on regional grids and require constant balancing between supply and demand. Therefore, the transition is changing not only which materials are needed, but also how energy moves between countries (Scholten et al., 2020).

The global demand patterns are influenced by this transformation. Clean energy technologies depend on lithium, cobalt, nickel, manganese, copper, graphite, and rare earth elements (REEs) for batteries, magnets, motors, and grid infrastructure. Under a climate-aligned scenario (i.e., the pathways that follow global climate goals), the IEA projects that clean energy is expected to account for most of the world's lithium, a large share of cobalt, and rare earth elements (REEs) by 2040. Therefore, the mineral market is no longer an ordinary industrial commodity and has become a central part for energy security. Not only the type of energy but also the structure of dependence itself has changed. Renewable resources (e.g. sunlight and wind) are almost equally distributed, but the 'industrial supply chains' needed to convert them into usable electricity are geographically concentrated and technologically complex (IEA, 2021).

2.2.2. The Material Paradox

This thesis conceptualizes the energy transition as a "material paradox," referring to a shift from dependence on fossil fuels toward dependence on geographically concentrated critical minerals required for renewable energy technologies. This term captures the tension at the heart of the green transition, meaning that a reduction in exposure to oil and gas volatility increases dependency on minerals that are geographically concentrated and industrially demanding. Early scholars often argued that decentralization created by renewable energy can soften or even decrease geopolitical rivalries. Scholten and Bosman (2016) argue that renewable energy may change the "play of the game" because most countries have access to some renewable resources, creating a "make-or-buy" choice between domestic production and electricity imports from more favorable regions (i.e., regions with better renewable conditions). However, more recent research argues that the energy transition is not reducing the importance of geopolitics, but changing its form. Instead of competing mainly over territorial control of oil and gas resources, states may increasingly compete over technology, manufacturing capacity, and control of strategic industries. In this context, renewable energy systems could create more mutual forms of interdependence than the unequal dependencies often seen in fossil fuel trade, since more countries have alternative ways to produce energy domestically (Overland, 2019). This shift can reduce dependence on a narrow group of fossil fuel exporters and increase the importance of regional electricity networks (e.g., transmission grids and cross-border power lines). At the same time, renewable energy systems generate new forms of interdependence, as electricity becomes a more dominant energy carrier and countries must cooperate through interconnected and technically complex power systems (Scholten and Bosman, 2016).

From an economic point of view, Pommeret, Ricci, and Schubert (2021) frame the energy transition as a process that happens under several scarcity constraints, especially limits on the carbon budget and on critical materials. Climate policy introduces a carbon budget that aims to limit cumulative emissions, which requires renewable technologies, but the expansion of renewable technologies relies on critical raw materials. Therefore, the transition depends not only on emissions reduction policies but also on the availability of minerals, the possibility of substitution (through backstop technologies) if needed, and recycling to reduce resource pressure. Their model does not assume that the world will run out of minerals; instead, it shows that ignoring mineral scarcity can mislead the climate policy design and underestimate the transition costs. The process is shaped by carbon constraints and material constraints. Renewable infrastructure requires minerals that are limited in supply and strategically important. Clean energy technologies such as wind, solar, hydrogen, and electricity systems require far more minerals than traditional fossil-fuel-based energy systems, increasing demand for a wide range of critical raw materials (World Bank, 2017). At the same time, many of these minerals continue to be extracted in regions affected by weak governance, environmental degradation, and, in some cases, conflict and instability. Despite efforts to improve governance standards and corporate practices, these challenges remain closely connected to global mineral supply chains (Sovacool et al., 2020). There are several factors that make the paradox serious and more concrete. Having mineral resources underground (known as geological abundance) does not necessarily mean they are economically available. Many minerals widely exist in the earth's crust, but they are often found in an amount that is not economically viable to extract. Production—and especially processing—is highly concentrated. According to IEA (2021), more than 70% of the global cobalt is mined in the Democratic Republic of Congo, while China accounts for roughly 90% of rare earth elements (REEs). China also refines approximately 60-70% of lithium and cobalt and around 30-40% of global nickel output. The data does not necessarily prove that countries use their position to force others, known as coercive leverage, but it shows a clear asymmetry in supply chain control.

The earlier empirical research confirms this pattern. The dataset examined 20 non-European countries rich in different types of minerals and showed that key materials like lithium and cobalt are highly concentrated: both reserve share and production capacity are often held by a small number of countries such as China and Australia. While geological endowment is varied, meaning that minerals can be found in many regions, the effective control on the extraction and downstream processing is concentrated, creating a systemic vulnerability for the countries that are dependent on imports.

At the same time, mining projects usually take a long period of time, often more than a decade, due to long permitting processes and infrastructure development, and markets cannot respond to urgent demands or supply disruptions quickly. In addition, the extraction and process of materials are followed by environmental and social pressures, such as water use, waste generation, and local ecological degradation. Therefore, expanding renewable infrastructure means dealing with material constraints that are economic, environmental, and geopolitical all at once. Import-dependent countries may still maintain some strategic flexibility because they can expand domestic renewable energy production if external supply risks increase, which can help reduce long-term vulnerability (Overland, 2019).

2.2.3. Systemic Vulnerabilities in the Material-Intensive Model

This shift introduces some vulnerabilities that are different in important ways from those of fossil fuel markets. One of the issues is supply chain rigidity. Unlike oil, which is extracted, traded, and consumed continuously, there is a characteristic that makes the critical raw materials unique: they are placed into long-lived infrastructure such as batteries, electric vehicles, and wind turbines, and once installed, they are locked in for years. This reduces the short-term flexibility, and a sudden supply disruption will be challenging to manage.

The second vulnerability is processing concentration. Mining is geographically dispersed for certain materials, but refining and midstream processing are usually centralized. For example, China holds a dominant position in the processing of rare earth elements (REEs) and refines a significant share of lithium and cobalt (IEA 2021). This concentration is especially visible in the cases of lithium and cobalt. Most of Australia's lithium production is exported to China for refining, while the Democratic Republic of Congo—despite dominating global cobalt mining—sends nearly all of its output to Chinese refineries. As a result, even when mining production is geographically distributed, the supply chain itself can remain highly concentrated (Le Mouel & Poitiers, 2023). The existence of such industrial chokepoints does not necessarily lead to coercive power, but it can create strategic sensitivity for the supply chain by limiting adjustment options in the case of disruption.

Moreover, mineral markets lack institutional architecture and are considered less organized than oil. For oil, there is a coordinated emergency stockpile mechanism by the International Energy Agency to respond to supply disruption, but there is no similar global mechanism for critical materials. Therefore, the response to shocks might be slower and more fragmented. Technological substitution and recycling can provide a long-term solution for vulnerabilities, but it needs time, investment, and regulatory support that make it challenging. Finally, the environmental and social impacts of extraction are uneven and unequally distributed, often concentrated in regions like the Democratic Republic of Congo, with weaker regulations and governance capacity. For actors such as the European Union—where decarbonization strategy depends on electrification and industrial transformation—these structural factors create a situation where resilience and strategic autonomy become important. The problem is not only whether the materials exist, but also how concentrated their supply chains are, how adaptable they are, and how politically stable they can remain (IEA 2021).

2.3 The New Geopolitics: Materials Security, Resource Weaponization, and Strategic Autonomy

In Europe, critical raw materials (CRMs) are now viewed as strategic assets rather than just technical industrial inputs, as they are linked to security and long-term economic stability. The urgency of this policy shift becomes clearer when looking at future demand projections. EU lithium consumption alone is expected to increase up to twelve times by 2030 and potentially twenty-one times by 2050, mainly because of the rapid expansion of electric vehicles and battery technologies (Righetti & Rizos, 2023). The European Commission's Communication on Critical Raw Materials (2020) points out that access to CRMs is necessary for achieving the objectives of the European Green Deal, industrial competitiveness, digital transformation, and energy security. At the theoretical level, this policy framing is very significant because it interprets economic dependency as a form of vulnerability. Market structure is now just a part of the supply chain, as areas such as exposure, uncertainty, and limited control can create strategic risks. As a result, issues related to energy security are no longer simply about energy production but also about the industrial networks that support low-carbon energy solutions.

The way policymakers frame the issue changes how people think about dependency. Fuel access and physical supply routes were the main determiners in the traditional discussion of energy dependence. Currently, the dependency relates to an industrial ecosystem that includes processing capacity, technological expertise, manufacturing integration, and regulatory environments. Therefore, countries that rely on imports of critical raw materials face a less visible type of vulnerability compared to physical supply disruption, but one that is equally relevant in long-term strategic planning. Scarcity is not the only problem; there are concerns about the stability and adaptability of the global supply network under geopolitical competition, the changes in industrial policy, and technological transformation.

Within this setting, this thesis aims to introduce the concept of the materials security dilemma. This term explains a situation where the import-dependent actors are uncertain about the future access to critical raw materials, and in response to this perception, they pursue some precautionary strategies to reduce exposure. These responses include diversifying suppliers, supporting the domestic capacity of processing and refining, expanding recycling efforts, tightening investment screening, and adopting targeted industrial policies. Although these measures are presented as defensive and resilience-oriented, they can alter patterns of global cooperation when adopted simultaneously by multiple actors. The outcome is dynamic, where attempts to increase security may indirectly intensify competition or fragmentation, even in the absence of openly confrontational behavior. The logic resembles the classical security dilemma because policy responses are shaped by uncertainty rather than explicit hostility.

The European debate on strategic autonomy is directly linked to the materials security dilemma framework. Instead of advocating for total self-sufficiency (economic isolation), the European Commission promotes the concept of "open strategic autonomy,"[5] aiming to reduce excessive dependencies and keep participation in global markets (European Commission 2020). A CEPS analysis by Alcidi and Kiss-Gálfalvi (2023) confirms this interpretation, arguing that dependency should be assessed not only by import levels but also by concentration and substitutability: "In addition to the extent to which EU countries import a certain good or product, one should consider whether such imports are concentrated in a few or just a single supplier (at country level) and the extent to which production could take place in the EU (the potential substitutability of imports)." The report further notes that "the combination of high relative import demand-dependency, high concentration, and low substitutability is a good recipe for dependency,"

[5] The concept of strategic autonomy originally emerged in European debates on security and defense policy. Over time, the European Union expanded the concept to include trade, technology, and industrial policy under the term "open strategic autonomy." The idea is to reduce dependence on external actors in critical sectors while remaining committed to international trade and economic openness.

while emphasizing that “not all dependencies should be of concern for the purpose of achieving strategic autonomy—only high dependency on products belonging to sectors that can be qualified as being strategically important” (Alcidi & Kiss-Gálfalvi 2023). Therefore, the goal is not to reach strategic autonomy through the rejection of interdependence but to implement a management strategy. It ensures a high level of resilience and policy flexibility so that external shocks, political tension, or market disruption do not affect the economy and cause strategic consequences. This policy approach later was later formalized in the EU’s Critical Raw Materials Act (CRMA), which aims to strengthen supply-chain resilience and reduce strategic dependencies. However, critics argue that these domestic targets alone are not enough. Since Europe’s exposure to critical raw material bottlenecks operates mainly through global supply chains rather than direct imports of raw materials, a strategy focused only on domestic mining and refining cannot fully address the deeper structural vulnerability (Le Mouel & Poitiers, 2023). An effective response therefore also requires an international dimension, including the diversification of refining and processing capacities beyond Europe itself. The implications of this policy response are examined in detail in Chapter 3.

When the supply chains are started to be seen through a security lens, the question about resource weaponization automatically emerges. The literature remains divided between perspectives that see renewable energy as reducing geopolitical tensions through more decentralized energy systems and those that argue the transition is creating new tensions related to critical raw materials, infrastructure, and technology (Vakulchuk et al., 2020). In this thesis, resource weaponization refers to the deliberate use of export controls, regulatory restrictions, investment barriers, or trade measures to influence dependent actors. This dynamic can also be understood through the concept of “weaponized interdependence,” which explains how global economic networks can create unequal forms of power. As Farrell and Newman (2019) argue, these networks often develop around a small number of highly connected hubs that become essential to the functioning of the wider system. States that control these hubs can use them as “chokepoints” to restrict access to important flows of goods, capital, or information. In this sense, vulnerability comes not only from dependence itself, but also from the position actors hold within the network and their ability to influence or control these central points. But it should be taken into account that dependency by itself cannot guarantee effective coercion. The strategic pressure exerted by China on Japan in the 2010 rare earth episode is an important example of the strategic pressure and the limitations of such strategies. Although the initial increase in market concentration has raised concerns about leverage, subsequent moves and adjustments by firms and governments—diversification efforts and technological changes—reduced the long-term impact. Gholz and Hughes (2021) emphasize that coercive power is constrained by the capacity of markets and states to adapt. In this sense, vulnerability cannot be measured only by concentration levels, as it must also account for adaptability, innovation, and speed of adjustment.

This perspective changes the analytical focus away from considering dependency as something static and toward understanding how it interacts with resilience. Two actors with similar levels of exposure may experience different degrees of vulnerability, as it depends on their institutional capacity, policy coordination, industrial flexibility, and technological alternatives. Therefore, the literature suggests that deterministic interpretations, in which concentration automatically produces leverage, are not enough, and analysis should move beyond them. Adaptation mechanisms, including diversification, substitution, efficiency improvements, and recycling, play an important role in shaping outcomes and reducing the effectiveness of coercive strategies.

In Europe, resilience appears to be the central strategic objective. Current policy discussions focus on diversifying supply partnerships, supporting domestic capabilities of industrial capacity where possible, investing in recycling and circular economy models, and strengthening coordination across member states. The goal behind these measures is to reduce strategic exposure without cutting ties with the global economy. This logic implies that complete independence is neither realistic nor desirable. The aim is to manage interdependence in such a way as to minimize the degree of vulnerability while preserving economic efficiency and technological progress.

Taken together, these conceptual and policy developments show a reorientation in the geopolitics of energy. The question is no longer whether Europe is dependent on other actors for the critical raw materials because dependency is already acknowledged. The more precise question is what level of dependency leads to strategic vulnerability and under what conditions it can be reduced by policy choices, industrial adaptation, and coordinated governance. Research on resource leverage, such as Gholz and Hughes

(2021), showed that when adjustment is available and countries are able to adapt, even highly concentrated markets do not necessarily cause long-term coercive power. That said, the analysis moves from static measurements of exposure to dynamic evaluations of resilience.

The movement—from dependency toward resilience—frames the central question of this thesis:

How resilient is Europe to the potential weaponization of critical raw material supply chains, and which policy and industrial mechanisms can best strengthen its adaptation within a highly concentrated global market structure?

The selection of lithium, cobalt, and rare earth elements in the empirical chapters follows directly from earlier dataset findings, which identified these materials as presenting particularly high levels of concentration and strategic exposure within the contemporary energy system. These cases allow the thesis to examine how theoretical insights about vulnerability, adaptation, and strategic autonomy operate in practice.

Taken together, the three dimensions establish a coherent analytical trajectory. Classical resource geopolitics demonstrated how control over material inputs shapes power relations and strategic risk, while the resource curse literature highlighted how concentration can interact with governance and institutional quality. The contemporary context introduces a different configuration in which exposure emerges through industrial systems and global value chains. The materials security dilemma does not imply inevitable coercion, yet it generates structural uncertainty that encourages states to prioritize resilience, diversification, and industrial policy. It is within this evolving geopolitical environment that Europe's exposure to lithium, cobalt, and rare earth elements must be assessed.

3. Empirical Foundations of Case Selection

This thesis is grounded in the findings of a previous comparative research project conducted in 2025 on twenty non-European countries with major roles in the global supply of raw materials. That earlier project was designed as a multidimensional dataset combining information on mineral reserves, extraction and processing structures, technological and industrial uses, and a set of governance, social, economic, environmental, and security indicators. Its purpose was not limited to describing where raw materials are located; rather, it aimed to identify broader patterns linking material endowment to development outcomes, institutional performance, and strategic relevance within global supply chains.

The earlier research produced three findings that directly shape the analytical design of this thesis. First, it revealed that critical raw materials are not only unevenly distributed in geological terms, but are concentrated in ways that create clear geopolitical asymmetries. A small number of countries hold disproportionately large shares of key reserves or occupy dominant positions in extraction and downstream processing. The report showed, for example, that countries such as Chile and Argentina are central to global lithium supply, that the Democratic Republic of Congo occupies a highly concentrated position in cobalt, and that China plays a dominant role in rare earth elements and other strategically important materials (USGS, 2024). This pattern of concentration is crucial because it means that the politics of supply are structured not simply by scarcity, but by control over specific nodes of extraction, refining, and industrial transformation. In this sense, the earlier dataset supports the central argument of this thesis that the green transition does not eliminate dependency; it reorganizes it around a narrower and more strategically sensitive group of materials.

Second, the comparative dataset demonstrated that resource abundance does not systematically translate into institutional strength, social welfare, or environmental resilience. One of the clearest conclusions of the previous report was that resource-rich countries display sharply divergent outcomes across indicators such as human development, inequality, environmental performance, peace, climate vulnerability, and security. For example, the earlier comparative dataset showed that Australia and Canada have significant amount of raw materials high levels of human development and environmental performance, while the Democratic Republic of Congo—despite its dominant position in global cobalt supply—has much weaker governance conditions, lower peace indicators, and higher climate vulnerability. The significance of this finding for the present thesis is substantial. It suggests that the risks surrounding critical raw materials cannot be understood solely through the lens of market concentration or physical supply. Europe's future vulnerabilities also depend on the political, social, and environmental conditions of supplier countries, since instability, weak governance, and uneven development can amplify disruption risks and reduce the predictability of long-term access. Earlier research therefore helps move the analysis beyond a narrow concern with reserves and toward a broader understanding of structural exposure.

Third, and most importantly for the structure of this thesis, the earlier dataset showed that lithium, cobalt, and rare earth elements should not be treated as a single undifferentiated category of "critical materials." Although they are often grouped together in policy discourse, the comparative evidence suggests that they generate distinct forms of dependency. Lithium is associated above all with reserve concentration and midstream bottlenecks, meaning that vulnerability emerges not only from where the resource is located, but from the industrial stages through which it must pass before becoming usable in battery value chains. Cobalt represents a different configuration, in which extreme concentration coincides with governance fragility, security threats, and systemic instability in the principal supplier country. Rare earth elements, by contrast, illustrate a model in which strategic leverage arises less from simple reserve ownership than from the concentration of refining, processing, and industrial know-how. This differentiation is analytically important because it indicates that Europe is not facing one single dependency problem repeated across three materials. Rather, it confronts three distinct mechanisms of vulnerability: concentration in extraction, fragility in the supplier environment, and dominance in processing and downstream industrial capacity.

The value of the previous research, therefore, lies not only in showing that these materials are important, but in clarifying why they are important in different ways. This point provides the empirical foundation for the case-selection strategy of the thesis. Lithium, cobalt, and rare earth elements were selected because together they capture three different pathways through which material dependency can become a geopolitical problem for Europe. They allow the thesis to move from a general claim about critical raw materials to a more precise examination of how vulnerability is produced within global supply chains. The earlier dataset thus functions as an exploratory empirical bridge between the broader literature on resources, dependency, and governance, and the material-specific analysis developed in the following chapters. It demonstrates that Europe's emerging challenge is not simply dependence on imported inputs, but dependence on supply chains whose risks vary according to the structure of concentration, the institutional context of supplier countries, and the location of industrial chokepoints.

Seen in this way, the previous comparative project does more than provide background context. It helps establish the central claim of this thesis: that the energy transition generates a new security landscape in which different critical raw materials produce different forms of strategic exposure. This is precisely why the thesis adopts a comparative case-study approach centered on lithium, cobalt, and rare earth elements. Each of these materials illuminate a separate dimension of the broader material security dilemma discussed in this chapter, and together they make it possible to assess not only whether Europe is dependent, but how that dependency is structured and under what conditions it may become politically consequential. Table 1.1 provides a summary of these distinct dependencies and their relevance to this thesis.

Table 1.1. Analytical comparison of lithium, cobalt, and rare earth element dependencies

Material	Pattern identified in earlier comparative research	Main form of strategic risk	Relevance for this thesis
Lithium	Reserve concentration combined with midstream and processing bottlenecks	Supply-chain chokepoints	Shows how dependency can persist even when reserves are geographically broader than processing capacity
Cobalt	Extreme concentration in the DRC combined with weak governance, security threats, and fragility	Instability and disruption risk	Highlights how supplier-country conditions can intensify Europe's exposure
REEs	Strong concentration in processing, refining, and industrial capability, especially in China	Industrial and technological chokepoint	Illustrates how leverage may arise from downstream control rather than extraction alone

Source: Author's elaboration

The remainder of this thesis is structured into three chapters. Chapter II examines the geopolitical dimensions of mineral dependency through an analysis of the three case studies: lithium, cobalt, and rare earth elements. Chapter III evaluates the European Union's response to these challenges, focusing on the evolution of its critical raw materials strategy and the Critical Raw Materials Act (CRMA). Chapter IV explores future scenarios for Europe's materials security.

Chapter II

The Geopolitics of Mineral Dependency: A Case Study Analysis

This chapter examines Europe's dependence on critical raw materials and the vulnerabilities this creates for the green energy transition. It begins by outlining the extent of Europe's reliance on imports and the weaknesses embedded in its supply chains. The chapter then analyses three strategic raw materials—cobalt, lithium, and rare earth elements—to show how different forms of dependency emerge within global supply chains. The cobalt case highlights the risks associated with concentrated extraction and governance instability, lithium illustrates the challenges created by processing bottlenecks, and rare earth elements demonstrate the implications of industrial concentration and the potential weaponization of supply chains. By comparing these cases, the chapter shows that Europe's vulnerabilities do not arise from a single source but from different stages and structures of global supply chains, each creating distinct geopolitical and economic risks.

2.1 Europe's Dependence on Critical Raw Materials (CRMs)

The energy transition in Europe is highly demanding and requires a huge quantity of critical raw materials (CRMs). Renewable energy technologies, electric vehicles, and battery storage systems are highly dependent on minerals such as lithium, cobalt, and rare earth elements (REEs). Europe needs to produce lithium-ion batteries, wind turbines, electric motors, and other clean energy technologies, and to do so, these raw materials are highly essential. However, the problem is not only related to the demanding nature of mineral production but also the fact that the European Union produces only limited quantities of many of these materials domestically and therefore depends heavily on imports. Because of this situation, access to critical raw materials has become an important strategic issue for the European Union (European Commission, 2020).

According to assessments made by the EU, there is an extreme level of dependence on some critical raw materials. The European Commission stated that the European Union imports the vast majority of the critical raw materials it uses. For some materials, the dependency is close to total. For example, around 98% of the EU's rare earth element supply comes from China, and a large share of lithium is imported from countries such as Chile and Australia, alongside Argentina, which are among the world's largest producers. In the case of cobalt, the global production is highly concentrated in the Democratic Republic of Congo, accounting for around 70% of the global supply (European Commission, 2020; IEA, 2021)

The trade data further reveal that Europe relies heavily on the imports of these materials annually. According to Eurostat, the European Union imported about 12,900 tons of rare earths in 2024, with China still dominating the exports and supply. The lithium used for battery manufacturing in Europe is first imported as lithium carbonate and lithium hydroxide. The primary sources of these minerals are Chile, Argentina, and Australia. Cobalt supply is also heavily dependent on imports but refining and processing are largely concentrated in China before reaching European markets. This shows that in addition to dependence on mining countries, Europe is highly dependent on countries that refine and process the materials (Eurostat, 2025; IEA, 2021).

The primary factor that influences the need for critical raw materials in Europe is the development of renewable energy sources and electric mobility. Cobalt and lithium are essential elements in the lithium-ion batteries used in electric vehicles and energy storage systems. Although the European Commission anticipates long-term growth in the manufacture of electric cars in Europe, this anticipation is challenged by global competitors and market complexity. Nevertheless, estimations suggest that EV expansion alone can increase EU demand for cobalt twofold and for lithium sixfold (Le Mouel & Poitiers, 2023). The REEs are required in the permanent magnets that are used in wind turbines and electric vehicles. Given that the European Union plans to expand renewable energy and green transportation, the move towards a sustainable and green economy requires battery, solar panel, and permanent magnet production on a large scale. As these technologies rely on critical raw materials, ensuring secure access to these resources has become a central priority in the EU’s industrial and energy strategies. (European Commission, 2023).

The European Commission expects continued growth in the electric vehicle (EV) sector, but European companies face a heavy competition from Asian producers, particularly Chinese companies. In response, major European automakers have changed their industrial strategies to strengthen their position in the EV market and secure access to critical materials. For example, Volkswagen has established PowerCo to support battery-cell production and integrate key stages of the battery value chain within Europe (Volkswagen Group, 2022). Stellantis, together with Mercedes and Saft, created the Automotive Cells Company (ACC) to expand European battery manufacturing capacity (ACC, 2024). Renault has also launched Ampere, a dedicated electric vehicle division aimed at accelerating EV development and improving competitiveness (Renault Group, 2023). These initiatives show a broader effort by European companies to strengthen Europe’s resilience and stay competitive in green transition.

Several European countries have become especially vulnerable to such dependency due to the nature of their industries. Germany's large automotive sector relies heavily on lithium-ion batteries, Sweden and Finland are building battery manufacturing and mining projects, and France depends on rare earth elements for aerospace and energy technologies (European Commission, 2022; IEA, 2021). Understanding how this supply chain operates is important for evaluating Europe's strategic vulnerabilities. The following sections analyze three critical raw materials that illustrate different types of dependency within the global mineral economy: cobalt, lithium, and rare earth elements. Each case highlights a different dimension of supply chain concentration and geopolitical risk (see Table 2.1).

Table 2.1. Europe's Dependency on Key Critical Raw Materials (CRMs)

Mineral	EU dependency	Main supplier countries	Main uses in Europe
Lithium	High import reliance	Chile, Argentina, Australia	EV batteries, energy storage
Cobalt	Global supply concentrated (around 70% DRC)	DRC (processed in China)	Battery cathodes
Rare Earth Elements (REEs)	98% supplied by China	China	Wind turbines, electric motors

Source: Author's elaboration based on European Commission (2023), IEA (2021), and USGS (2025).

2.2 Cobalt: The Instability Nexus

The move towards low-carbon energy systems requires significant amounts of minerals for their production. Among these, cobalt is one of the important critical raw materials due to its use in lithium-ion batteries and other high-performance technologies. Cobalt has been used for many decades in industries for various uses like superalloys, catalytic, pigments, and also in chemical industries. However, over the past ten years, cobalt has gained new strategic significance with respect to the rapid expansion of rechargeable battery technologies used in electric vehicles, consumer electronics, and energy storage systems (Olivetti et al., 2017; IEA, 2021).

Lithium-ion batteries use different types of metals, namely lithium, nickel, manganese, and cobalt. For battery cathodes, cobalt provides thermal stability and energy density that helps batteries to function well and maintain performance through consecutive charging cycles. As the adoption of electric vehicles is an important element of decarbonization policies, there has been a considerable rise in the demand for these materials. Studies of the battery supply chain reveal that the future of battery manufacturing depends heavily on the availability level of the raw materials and also the supply risks related to the shortage in materials such as cobalt that may hinder the growth of electric mobility expansion (Olivetti et al., 2017). The International Energy Agency points out that cobalt is one of the most vulnerable to supply risks in case of rapid development of electric vehicle (IEA, 2021). Despite innovations aimed at lowering the amount of cobalt used in batteries, most cathode technologies still rely on significant quantities of cobalt, particularly in nickel-cobalt-manganese and nickel-cobalt-aluminum battery systems (IEA, 2021).[6]

Cobalt deposits can be found in many European countries, but most of these resources are not viable from an economic point of view. The identified cobalt deposits mining projects (e.g., Kevitsa and Terrafame mines) are not associated with enough concentrations and lack accurate resource estimates, which as a result, limits their contribution to the supply (Horn et al., 2021). In the meantime, the mined cobalt production growth in Europe is expected to stay limited because of the small and low-grade deposits, long project development times, and unfavorable investment conditions (Bille, 2025).

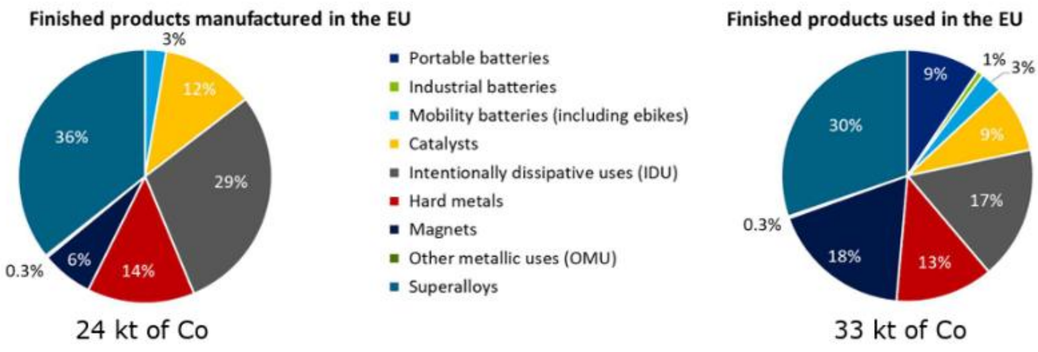

Figure 4: Shares of finished products containing cobalt manufactured in the EU (left) and shares of finished products containing cobalt used in the EU (right), by application.

Figure 2.1. Shares of finished products containing cobalt manufactured and used in the EU by application. Source: European Commission, JRC (2018).

Figure 2.1 illustrates that battery-related applications, especially in mobility and industrial batteries, predominantly drive cobalt use in the European Union. This reflects the growing importance of electric vehicles and energy storage systems within the European energy transition. This pattern highlights the structural link between cobalt demand and the expansion of low-carbon technologies in Europe.

[6] In lithium-ion batteries, the cathode plays a major role in determining how much energy the battery can store and how efficiently it performs. NCM (Nickel-Cobalt-Manganese) and NCA (Nickel-Cobalt-Aluminum) are widely used in electric vehicles because they provide high energy density. Cobalt is particularly important because it helps stabilize the battery and reduces the risk of overheating.

Nevertheless, rechargeable batteries are now the main source of demand—and even the fast-growing one—for cobalt (Liu et al., 2022). Empirical research on cobalt mining also shows that more than half of the global cobalt production is now directed toward battery manufacturing, particularly for portable electronics and electric vehicles (Nkulu et al., 2018). Therefore, the cobalt market is connected closely to the broader transformation of the global energy system.

2.2.1 Global Cobalt Supply

What makes the cobalt market unique is its extraordinary geographical concentration. As of 2024, the Democratic Republic of Congo accounts for about 70% of all cobalt production from mines around the world. The second largest producer is Indonesia with about 10% of global production, while other mining countries like Russia, Australia, and Canada contributed considerably smaller shares (USGS, 2025). Previous estimates made by the European Commission already identified the high concentration in the production of cobalt. In 2016, the DRC accounted for about 55% of global cobalt mine production and this percentage has increased over the years due to the increase in demand for battery materials (Alves Dias et al., 2018). More recent research shows that the Congolese share exceeded 70% in the early years of the 2020s, confirming the country's dominant position (Deberdt & DiCarlo, 2024; Cobalt Institute & BloombergNEF, 2024). The concentration pattern is even more reinforced by the distribution of the mineral reserves. The geological survey show that around half of the world's known cobalt are found in DRC, mainly in the Central African Copperbelt region, which stretches from southern Congo to northern Zambia (Horn et al., 2021). This extreme geographical concentration in global mine production is illustrated in Figure 2.2.

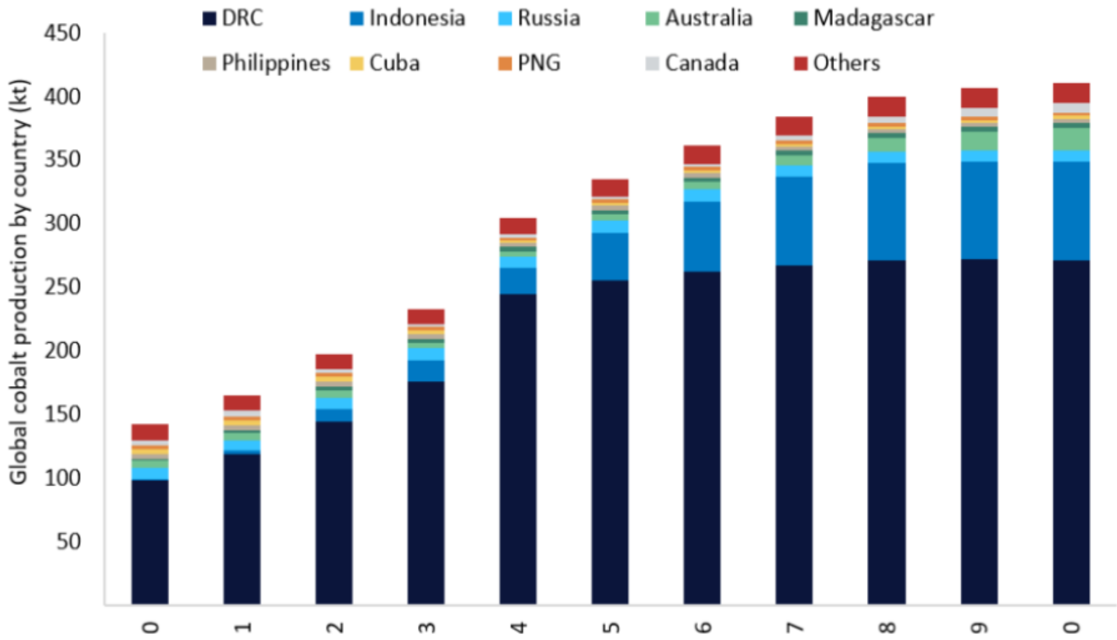

Figure 2.2. Global cobalt mine production by country.

Source: Adapted from Mining Technology using data from USGS Mineral Commodity Summaries (2025).

The structure of cobalt supply is also one of the drivers of this geological nature of cobalt deposits. In most mining operations, cobalt is produced as a by-product of copper and nickel extraction—not a primary metal—and approximately 99% of global cobalt output is derived from copper and nickel mining (Ryter et al., 2025). It shows that the level of cobalt production often depends on other metals' production and their economic dynamics. There is only one mine in the world where cobalt is the primary product, the Bou Azzer mine in Morocco, and the rest of the considerable volume of cobalt is determined and limited by the output of the host metals (Ericsson et al., 2024; Tourneur et al., 2021). Studies of the cobalt supply chain show that an increase in cobalt demand does not necessarily lead to an increase in production because cobalt production responds weakly to increases in its own price and is instead tied to the economics of the host minerals from which it is extracted as a by-product (Ryter et al., 2025). Therefore, the by-product nature of cobalt makes its supply inflexible — a sort of structural rigidity — meaning that it cannot easily scale up to meet sudden increases in demand, which can result in shortages.

2.2.2 Structure of the Cobalt Supply Chain

The global cobalt industry has a multi-stage supply chain that connects key actors, from mining regions to final industrial consumers. These stages include the extraction of cobalt ore, its refining and chemical processing, the production of battery materials, battery manufacturing, and finally its integration into electric vehicles or electronic devices (Olivetti et al., 2017). The structure of this multi-stage network, along with a potential European supply-chain pathway, is mapped out in Figure 2.3.

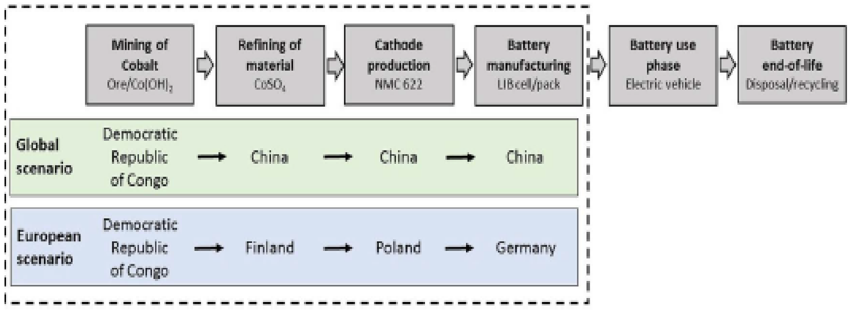

Figure 2.3. Structure of the global cobalt supply chain and a possible European supply-chain pathway. Source: Adapted from da Silva Lima et al. (2023).

The Democratic Republic of Congo dominates global cobalt mining, but the refining and processing of this material largely takes place outside Africa, particularly in China. This means that the DRC exports raw or semi-processed cobalt to China, where the materials are refined and transformed into battery-grade materials. This gives China a dominant position in the intermediate stages of the cobalt supply chain and control of the link between the mine and the battery factory (van den Brink et al., 2020). This refining process produces battery chemicals such as cobalt sulfate, which are then used in battery manufacturing. According to European Commission, China alone accounted for around half of global refined cobalt production, while the DRC, as the world's largest mining country, contributed only a small share of refining (Alves Dias et al., 2018). This gap has not narrowed by now; more recent data show that China is still dominant in the refining stage; however, its industry relies heavily on imports from the DRC (USGS, 2025). In other words, these two countries are deeply interlinked, as the DRC needs China to transform the material into something the global battery industry can use, and China needs the DRC for the mining and supply.

Furthermore, Chinese companies have expanded their investments in mining activities in the DRC and currently control many large cobalt mines in the Copperbelt region. The investments have given China a strong position in the Cobalt supply chain and also integrated the mining production of Congo into Chinese manufacturing demand.

2.2.3 The Resource Curse and Cobalt Governance in the DRC

On paper, the Democratic Republic of Congo is extraordinarily wealthy, as it holds the world's largest cobalt reserves and produces most of the global cobalt (USGS, 2025). But the country is still among the most fragile and conflict-affected states in the world and is constantly ranked the bottom of global peace and security indexes (Institute for Economics & Peace, 2024). This contradiction cannot be ignored, and it is not unique to the DRC. As demonstrated by the earlier comparative research, many other resource-rich countries—such as Russia and Brazil—share this dynamic. The previous dataset showed that high mineral endowment is frequently linked to weak governance indicators, fragility to security threats, and uneven development outcomes.

This kind of paradox can be explained precisely by the resource curse literature. Having a large share of resources does not necessarily lead to development – under certain situations it can even reverse the development process of a country (Ross, 2015; Le Billon, 2001). When states rely on resource rents rather than taxation, they face weaker pressures for accountability and it usually leads to patronage, weakening the institutions that could manage revenues responsibly (Teorell, 2010). This cycle seems to be firmly rooted in the DRC. While cobalt resources have not resulted in any form of good governance or socio-economic development, extraction operations happen under poor regulation, health hazards for laborers, and negligible government control (Sovacool et al., 2020).

What makes this issue more important for this thesis is its global supply dimension of these domestic failures. Instability in the DRC is not just a humanitarian concern; it is considered a risk for the global supply chain. Political disruptions, changes in mining regulations, or outbreaks of conflicts inside the country can rapidly lead to shortages for the industries and countries that rely on the cobalt imports (van den Brink et al., 2020; Liu et al., 2022). For Europe, which sees cobalt as a vital input for battery technologies and energy transition processes, vulnerability in its main supplier, DRC, represents a structural challenge that cannot be solved solely by market mechanisms.

2.2.4 Implications for European Energy Security

For the European Union, these dynamics in supply have created a complicated strategic challenge. According to the European Commission, the demand for cobalt to use for electric vehicles reached more than 50,000 tonnes annually in the mid-2020s, and it is estimated that it will keep growing toward 2030 (Alves Dias et al., 2018). In the meantime, cobalt production inside Europe is extremely limited. Finland is one of the few European countries that actively mine and refine cobalt. As a result, Europe's total share is a small fraction of global production of cobalt (Horn et al., 2021).

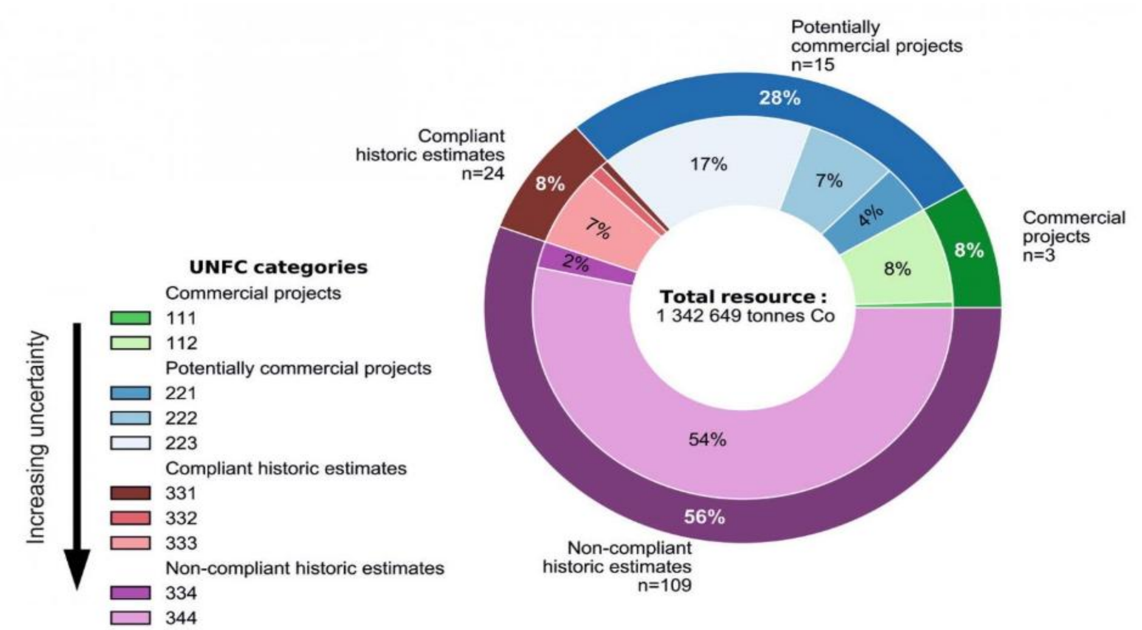

Figure 2.4. Cobalt resources in Europe classified using the UN Framework Classification (UNFC). Source: Horn et al. (2021).

Figure 2.4 shows that although Europe has cobalt resources, much of these deposits remain uncertain in terms of their geological conditions and economic viability. Only a small share is currently considered commercially viable. As a result, European industries still depend heavily on cobalt mined in the Democratic Republic of Congo and processed mainly in China. This exposes European battery and automotive industries to several external risks, since political instability, supply disruptions, trade tensions, or regulatory changes could all affect the availability and price of cobalt on international markets.

Even with policy initiatives aimed at strengthening domestic supply, Europe will continue to rely on imports of mined cobalt and cobalt intermediates from third countries. While there is potential to increase capabilities in processing and recycling, mined cobalt supply within Europe is expected to meet only a fraction of future demand (Bille, 2025). In this context, cobalt can be understood as a key example of the material dependency that accompanies the transition toward low-carbon energy systems. Europe's shift away from fossil fuels does not eliminate geopolitical vulnerability; rather, it reshapes that vulnerability around new supply chains centered on critical minerals. The Democratic Republic of Congo and China occupy central positions within the cobalt industry, and the political, economic, and social dynamics within these countries therefore play an important role in shaping the future of global battery supply chains.

2.2.5 Challenges to Cobalt Supply Security

The structural characteristics discussed in the earlier sections—extreme concentration of mining in the Democratic Republic of Congo, China's dominance in refining and processing, the by-product nature of cobalt extraction, and growing demand of Europe for batteries—together make a web of interdependencies and compound one another, creating vulnerabilities that are much harder to resolve than any individual factor in isolation. Four main challenges define this picture, and none of them have a simple or straightforward solution.

Price Volatility and Structural Market Instability

When it comes to price, cobalt behaves in a different way than most industrial metals, and its explanation has nothing to do with its demand. The main problem is related to how cobalt is actually produced. Cobalt has almost never been mined independently—

it is usually produced as a by-product of copper and nickel mining. It means the amount of cobalt produced entirely depends on what is happening in copper and nickel markets and not on EV demand (Slack et al., 2017). When the demand for copper increases, mines raise up their production, and cobalt floods the market as a consequence, regardless of whether there is a need for it. When copper slows down, cobalt production is decreased accordingly, even if the battery manufacturers need more of it (Ryter et al., 2025; Ericsson et al., 2024). This mismatch between supply dynamics and demand requirements is structural, not cyclical, and it makes price stability exceptionally difficult to achieve.

The cobalt price cycle in the late 2010s shows this dynamic very clearly, where the expectation of a rise in electric vehicle (EV) demand pushed the prices up, and after the expansion of supply, prices collapsed very quickly. For European manufacturers that are planning to invest in gigafactories and long-term supply contracts, these price volatilities create real costs that go beyond the short-term financial results—creating lasting costs that are difficult to plan around. Research based on International Energy Agency energy transition pathways projects that total material demand in the transport sector —mainly driven by EV development—could increase up to 700 percent by 2050 (Watari et al., 2019), with cobalt at the center of this demand surge. However, the supply system is structurally inflexible and cannot easily respond to changes in demand, which as a result, makes it unable to handle such pressure without generating repeated and intensifying price instability. In this sense, the recent boom-bust cycle should be considered as an early warning rather than an anomaly.

The Refining Bottleneck and China's Processing Dominance

The common view in the public debate is that Europe's vulnerability on cobalt is mainly a result of mining geographical concentration in the DRC, and the solution is to diversify the cobalt sources and include more exporting countries. While this view is not wrong, it misses a deeper issue: even if Europe managed to import cobalt ore from many mining countries, the material is not ready to be directly used in batteries. The ore should first go through the refining process to be turned into battery-grade chemicals, and most of the world's capacity to do this refining is concentrated in China (Alves Dias et al., 2018; USGS, 2025).

European Commission assessments have confirmed that China accounted for close to half of global refined cobalt output by the late 2010s, while the DRC—despite dominating mining—contributed almost nothing to refining capacity (Alves Dias et al., 2018). More recent data confirm that this situation has not changed (USGS, 2025). Chinese companies have deepened this position by investing directly in Congolese mining operations, effectively integrating the supply chain from extraction through to processed battery materials under a single industrial logic (Deberdt & DiCarlo, 2024). Diversifying mining sources while leaving refining capacity untouched would not solve Europe's dependency — it would just move the chokepoint slightly upstream. As research on mineral-intensive energy systems has emphasized, processing concentration of this kind fundamentally limits the adjustment options available to import-dependent actors when disruptions occur (Giurco et al., 2019). Europe's exposure is embedded in the industrial architecture of the supply chain, not just its geography.

Political Instability and Governance Fragility in the DRC

The two above challenges are compounded by a more fundamental problem. A single country owns around 70 percent of global cobalt and the country struggles with serious and continuous governance and stability challenges. The regions where cobalt is extracted are marked by weak institutions, corruption, unequal distribution of mining revenues, and recurring security pressures (USGS, 2025; Sovacool, 2019). As explained in Chapter 1, when institutions are weak, having abundant natural resources does not automatically lead to stability. In fact, it can make things worse by encouraging competition over resource revenues and distorting governance in ways that increase rather than reduce risk. The DRC's experience with cobalt fits this pattern well.

The situation in which cobalt is extracted adds another layer of complexity to this picture. It is estimated that Artisanal and Small-Scale Mining (ASM)[7] accounts for around 15-20% of cobalt production in the DRC, causing serious human costs, including dangerous working conditions, child labor, and toxic exposure for surrounding communities (Nkulu et al., 2018; Pact, 2017). Under the EU's Corporate Sustainability Due Diligence Directive[8], the European companies are now required to identify and address these risks in their supply chains (European Union 2024). However, in practice, it is difficult to achieve because the cobalt supply chain passes through multiple intermediate trading and processing stages that are not quite transparent. Therefore, it is hard for companies to trace exactly where their material comes from and under what conditions it was produced. The policy implications of these challenges are taken up in Chapter 3.

From a supply security point of view, the picture is clear but concerning. A single change in regulations, a dispute over a mining contract, or an infrastructure breakdown in one involved country is enough to disrupt the whole supply of a material that European battery and automotive industries are highly and increasingly dependent on. Research on cobalt material flows has warned that political instability or sudden policy shifts in major supplier countries, including the DRC, can cause a serious risk and disruption to the global cobalt markets (Liu et al., 2022). The absence of a safety net makes this especially worrying. Unlike oil, where the IEA has emergency stockpiling and crisis response mechanisms, there is not any equivalent system for critical minerals. It means that if a supply shock occurred, the response will likely be slower, more fragmented, and less effective. Europe cannot fall back on its own production either. The vast majority of identified cobalt deposits on European soil are either geologically uncertain or economically unviable, and domestic output is expected to remain a marginal share of global production for the foreseeable future (Horn et al., 2021; Bille, 2025). With EU

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[7] Artisanal and Small-scale Mining (ASM) refers to mining carried out by individuals or small groups using simple, labor-intensive methods rather than large-scale industrial machinery. In the Democratic Republic of the Congo (DRC), much of this activity takes place outside formal regulatory systems, often exposing miners to unsafe working conditions and increasing the risk of exploitation.

[8] The Corporate Sustainability Due Diligence Directive (CSDDD) is an EU legislative framework that mandates large companies operating within the EU to actively mitigate negative human rights and environmental impacts across their global value chains, shifting voluntary ESG standards into legal obligations.

cobalt demand from electric vehicles already projected to exceed 50,000 tons per year at this stage (Alves Dias et al., 2018), the lack of any domestic alternative is becoming increasingly hard to overlook.

These challenges are not separated from one another and cannot be solved independently. They are deeply connected and strengthen one another. Price volatility makes it difficult for companies to invest in alternative supply chains in the long term. The refining bottleneck implies that increasing the number of source countries for cobalt ore will not decrease Europe’s reliance, as the chain will continue to pass through China regardless. Meeting the criteria for ESG compliance increases costs and risks associated with sourcing cobalt from the same area where it is highly concentrated. Finally, weak governance in the DRC puts the whole chain of operations on an uncertain foundation. Taken together, these challenges create a condition that is difficult to resolve through a single policy measure. These challenges have pushed the EU to respond with a range of policies and measures, but there is ongoing debate about whether these responses are strong enough to actually address the problem. Chapter 3 examines those policies.

2.3 Lithium: The Midstream Paradox

At first view, lithium seems to present a more reassuring picture than cobalt. Unlike cobalt, which is highly concentrated in a conflict-affected state and creates an obvious and visible vulnerability, lithium reserves are spread across many countries, including Chile, Bolivia, Argentina, Australia, and other countries. The main supplier countries are politically stable, institutionally capable, and integrated into the global economy. Governance crisis, artisanal mining emergencies, and fragile states dominating the narrative are not considered a challenge in this case. On paper, it appears to be that type of diversified supply base that would reduce the strategic risk.

Nonetheless, Europe's dependence on lithium is just as critical as its reliance on cobalt; it is just differently structured. The vulnerability is not where it seems to be. Lithium reserves and production alone do not tell the whole story since lithium mined from Chilean salt flats or Australian hard-rock deposits cannot be immediately utilized in battery production. Lithium extracted from the ground needs to undergo chemical processing into battery-grade lithium compounds—mainly lithium carbonate and lithium hydroxide—and this conversion process occurs mostly in China. It is not in the mine but rather in the chemistry where the bottleneck lies. Geological abundance distributed in the countries stable geopolitically does not ensure supply security when the industrial stage that converts the rock into a usable material is controlled by a single actor (Sanchez-Lopez, 2023; IEA, 2021).

This is what described as the midstream paradox of lithium in this section[9]. This term points to a specific type of dependence where the risk is not in the extraction stage—since the reserves are distributed genuinely—but in the refining and processing stage, where concentration is extreme and alternatives are limited (Heydari et al., 2025). This type of vulnerability is less visible than cobalt's. It is hard to explain it through the usual story of resource scarcity and even harder to address it through policy because it does not announce itself through the instability of supplier states. The structural limitations of lithium supply are not geological—as resources already exist in enough quantity—but industrial and temporal, which are rooted in long lead times, processing bottlenecks, and slow reaction of the supply chain to changes in demands (Greim et al., 2020). For Europe, which is estimated to need lithium twelve times more than its current consumption by 2030 and potentially 21 times by 2050, primarily as a result of the expansion of electric cars, these concerns are not just abstract. (Righetti & Rizos, 2023). They define the terms on which the energy transition will either succeed or face serious disruption.

The following sections will focus on how this dilemma operates in practice. In particular, the global spread of lithium resources and production will be evaluated, followed by an evaluation of the midstream bottleneck, where Chinese industrial hegemony is most concentrated. Furthermore, the evolution of European lithium demand and domestic limitations, and identify the specific challenges that make lithium supply security genuinely difficult to achieve. Lastly, this section will conclude with a discussion

[9] In commodity supply chains, "upstream" refers to the extraction and mining of raw ore; "midstream" involves the refining, smelting, and chemical processing of that ore into industrial-grade materials; and "downstream" refers to the final manufacturing of components, such as battery cells or electric vehicles.

comparing lithium and cobalt, drawing out the distinct mechanisms through which each material generates strategic exposure for the European Union.

2.3.1 The Global Lithium Landscape: Reserves Without Security

Lithium is not a rare element. This material is the twenty-fifth most abundant element in the earth's crust and found in dozens of countries in enough concentration that, on paper, is enough to support the energy transition for decades (Flexer et al., 2018). That is why lithium is not considered as urgent problem as cobalt; the reasoning is that a resource that exists across many stable and democratic countries is inherently more secure than in a single fragile state. But this reasoning has an important flaw. It confuses geological occurrence (how much lithium exists in the ground) with producible supply (how much can be really extracted and produced), and for lithium that difference is very important (Woodley et al., 2023).

The lithium reserves are not as evenly distributed as they are generally narrated. The world total reserves are estimated to be around 30 million tons, with Australia holding the biggest share and followed by Chile and Argentina (USGS, 2025). In terms of production, Australia dominated the world's lithium production by 88,000 tons in 2024; Chile produced 49,000 tons, and China with 41,000 tons (USGS, 2025). The so-called "lithium triangle," hosting the salt flats spanning Argentina, Bolivia, and Chile, is estimated to hold around 80% of the world's lithium brine resources (Flexer et al., 2018). This pattern of concentration is consistent with the findings of the earlier comparative research conducted for this thesis, which identified Chile and Argentina as holding 31% and 21% of global lithium reserves respectively. It confirms the Lithium Triangle's dominant position in the global supply landscape. Table 2.2 illustrates this distribution across the key producer countries.

Table 2.2 Global Lithium Reserves and Mine Production by Country (2024)

Country	*Reserve share*	*Main production (tons)*
Australia	Largest globally	88,000
Chile	31%	49,000
China	-	41,000
Argentina	21%	18,000
Brazil	-	10,000
Canada	-	4,300
Others	-	29,700
World total	30,000,000 tons	240,000

Sources: USGS Mineral Commodity Summaries (2025); Previous comparative dataset (2025)

The lithium within these countries is not spread evenly; it is concentrated in a few specific deposits. Three quarters of global lithium reserves are found in just ten large deposits, with only the Salar de Atacama in Chile accounting for around half of both global reserves and resources (Vikström et al., 2013). This is not a picture of comfortable diversification.

Though, the more fundamental issue is the difference between what geologically exists and what can be really produced and consumed. This can be explained using the example of the difference between the size of the tank and the size of the tap (Vikström et al., 2013). The tank means the total geological reserves that can look very large, but the tap is the actual rate of lithium that can be extracted and delivered to industry, which is completely different and limited. Resources are generally defined as geologically measured deposits but not necessarily exploitable in the current condition, while reserves are what can actually be produced today and are important for the real supply (Flexer et al., 2018). Only a small number of deposits are large and concentrated enough to be exploited commercially. In short, geological abundance does not necessarily mean supply security.

The technical realities of extraction make the issue even more clear. Around two-thirds of global lithium comes from brines—underground saline lakes found in highaltitude salt flats, particularly in the Lithium Triangle—rather than from hard rock minerals like spodumene, which dominate Australian production (Vera et al., 2023; Flexer et al., 2018).[10] Compared to other methods of extraction, brine extraction is cheaper, and that is why it dominates the global supply of lithium. But this method has some structural constraints that make scaling up (increasing the capacity of production) harder than it looks. The evaporation process, where brine is concentrated through solar radiation in large open-air ponds, "generally it can take anywhere from one to two years from the time the brine is pumped from the ground to the time the finished lithium product is processed" (Kaunda, 2020). When prospection and piloting are included, establishing a new brine operation from scratch can take a decade. Currently, there have only been five brine facilities that have been successfully established at an industrial scale across the world, and what applies to one salar will not necessarily apply to other salars since every individual salar has unique properties (Flexer et al., 2018). These are not minor technical stuff but something that makes challenges for the supply when there is a sudden demand for lithium.

Water is another constraint that is underestimated very easily. On average, brine extraction consumes half a million liters of brine per producing one ton of lithium carbonates, and up to 95% of that water imply disappears into the air and never returns to the ground. Then the process of transferring the concentrate into battery-grade material needs between five to fifty cubic meters of fresh water per ton of final product, in a region that is one of the driest place on earth (Díaz Paz et al. 2025, Flexer et al., 2018). The consequences of this situation are already visible. The volume of the water pumped from the Salar de Antacama has increased by 21% between 2000 and 2015, and in some regions, the underground level of water falls one meter per year (Kaunda, 2020). When the demand grows, these pressures will grow accordingly and make the new project approvals slower and more contested.

The numbers about demands make the issue more urgent and serious. The global lithium consumption was 220,000 tons in 2024, which shows an increase of up to 29% in

[10] Spodumene is a pyroxene mineral extracted through traditional hard-rock mining methods, which allows for faster processing but is more energy-intensive. Brines, on the other hand, are concentrated saltwater deposits extracted by pumping water into massive evaporation ponds, a process that is cheaper but heavily dependent on weather and extreme water consumption.

only one year, while currently batteries account for 87% of all end use (USGS, 2025). As per IEA's most ambitious climate scenario, it is projected that the demand will reach between 1.4 and 1.5 million tons by 2035—six to seven times more than current demand (IEA, 2025). Current lithium supply systems are too slow to stay in line with the demand pace as they are built around ten-year development timelines and weather-dependent evaporation ponds. This mismatch between supply and demand is projected to become problematic more seriously by 2030 and onward, not because the resources will run out but because the infrastructure for extraction and processing of the materials cannot scale up quickly enough (Greim et al., 2020). One number can show this fragility in a clear way: if the single biggest lithium-producing supplier stopped supplying, the rest of the world's suppliers together could only meet 67% of what is needed. 33% would simply be missing — there is no backup to fill that gap.

The picture shaped by these realities is far different from headlines about lithium abundance. It is true that the resources exist, but they are concentrated heavily, take a long time to be produced, and are affected by water scarcity. Europe, which does not have any lithium production and is projected to have demand grow twenty-one times more than current demand by 2050, cannot confuse geological existence of resources with supply security (Righetti & Rizos, 2023). And even this is only part of the problem. The lithium that is successfully mined in Chile or Australia does not arrive at European battery factories ready to use. It must first pass through a refining and processing stage that introduces a different and, in many ways, more intractable dependency — one that sits at the heart of the midstream paradox.

2.3.2 China's Dominance in Lithium Processing

Although extraction is reassuring and diversified on paper, there is another serious vulnerability. The lithium, which is extracted from the salt flats of the Atacama or the hard rock mines coming from Western Australia, does not arrive in Europe in a ready-to-use condition. The critical vulnerability lies in refining and processing, where lithium is converted into battery-grade lithium carbonate and lithium hydroxide. The risks in the lithium supply chain are not equal in all stages, as the downstream processing stages are riskier than mining. In other words, the closer the process moves toward manufacturing, the greater the risks and the higher the concentration (Sun et al., 2019). Mining geography shows the location of the material, but processing geography shows where the power is.

The numbers are hard to overlook. According to an assessment by the European Commission under the Critical Raw Materials Act, the dependency of Europe on import at extraction level reaches 81%, but in the processing stage, the dependency is 100%. Europe produces less than 0.1% of the global lithium and has no capacity to refine the mined lithium into the battery-grade compounds that its automotive and energy storage industries require (European Commission, 2025). This is not a partial vulnerability. It is a complete structural dependency on external actors for the industrial transformation of a material that is the center of the EU's decarbonization strategy. Public debate often treats extraction and processing as a single issue or neglects the distinction altogether.

The global sources of lithium in the extraction stage are relatively diversified. Australia accounts for around 53% of global extraction, followed by the Lithium Triangle (Argentina, Chile, and Bolivia) with smaller shares—the differences between the first two in the ranking are not high. However, the processing picture is different because the difference between the first country in the ranking (China with around 89%) and the second country (Chile with a small share through its SQM facilities) is huge (Sanchez-Lopez, 2023; European Commission, 2025). This gap between the diversified extraction stage and the concentrated processing stage is the main core of the midstream paradox. It means the reassuring picture of geographic spread of reserves and mines provides almost no protection for disruption at the stage that matters for battery manufacturing—clearly illustrated in Figure 2.5 below.

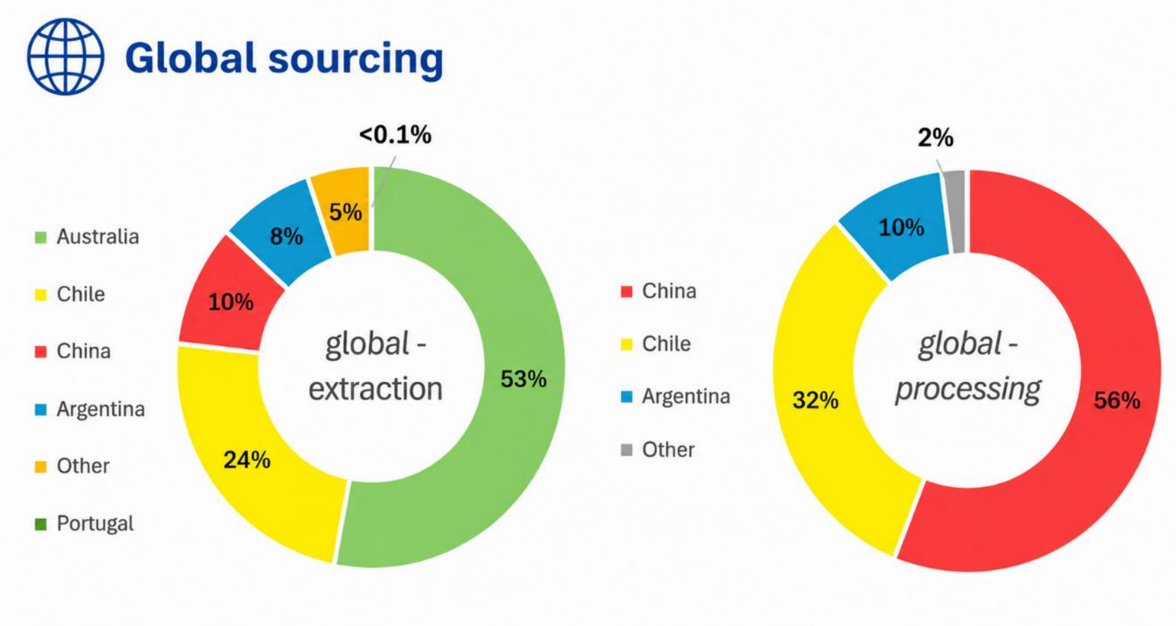

Figure 2.5. Global lithium sourcing: extraction vs. processing by country.
Source: European Commission (2025).

China occupies the central position in this processing bottleneck. Its dominance reflects decades of industrial coordination, technological accumulation, and investment in refining and battery manufacturing capacities that cannot be replicated quickly, even with significant financial investment (European Commission JRC, 2022; Sun et al., 2019).

The lithium-ion battery supply chain has six distinct stages: mining, refining, production of battery components, battery cell manufacturing, battery pack assembly, and electric vehicle manufacturing, and China dominates not just refining but multiple downstream stages at the same time (Sanchez-Lopez, 2023). Australia, the world's largest lithium producer, exports most of its spodumene ore to China for the processing stage (Le Mouel & Poitiers, 2023; IEA, 2021). Similar patterns exist in the Lithium Triangle, where countries like Chile and Argentina extract lithium carbonate from their salt flats, but much of the final transformation into battery-grade lithium hydroxide takes place in Chinese refining companies (Sun et al., 2019; Sanchez-Lopez, 2023). More than 65% of battery components such as cathodes, anodes, and separators are produced in China, and battery cell manufacturing is even more concentrated, as China accounts for 75% of global output (Sanchez-Lopez, 2023; European Commission JRC, 2022). The upstream stages of mining and refining represent only 2% of total value generated in the entire lithium-ion battery (LIB) supply chain, while the downstream stages of battery assembly and EV manufacturing account for 86% of the value (Sanchez-Lopez, 2023). The countries that hold the reserves capture only a limited share of the economic value, while the countries that dominate processing and manufacturing capture most of it.

This is exactly that kind of vulnerability that the concept of weaponized interdependence is designed to capture. Global economic networks are like "hub and spoke systems" where exchange "becomes centralized, flowing through a few specific intermediaries," and control over these central points creates chokepoints where a state can restrict access to critical flows of goods, capital, or information (Farrell & Newman, 2019). China's dominance in lithium processing gives it exactly such a position. The geographic concentration of critical raw materials, in some cases, is even higher than oil concentration, a resource that has historically caused major geopolitical crises when its supply was disrupted (Månberger & Johansson, 2019). There are already some examples of dominant mineral suppliers using their position for strategic and political purposes. In 2010, China's Tianqi Lithium bought a 24% stake in Chile's SQM—one of the world's largest lithium producers—for 4.1 billion dollars and integrated part of upstream mining directly into Chinese industrial networks; in other words, China extended its influence beyond processing into the mining stage itself (Sanchez-Lopez, 2023). The energy transition creates some risks that can cause a situation where raw materials become the new oil, reproducing structural vulnerabilities in a different material form (IRENA, 2019). The difference is that fossil fuel dependency was at least widely understood and institutionally managed through decades of policy development. Dependency on processed lithium is less visible, less institutionally managed, and considerably harder to address through conventional policy tools.

It should be made clear that concentration alone does not automatically translate into coercive leverage. Markets and states can adapt, and the effectiveness of supply disruption as a geopolitical tool can be lowered and limited by the capacity of dependent actors to adjust and diversify over time (Gholz & Hughes, 2021). But the structural vulnerability created by this concentration is real and important, whether an actor intended it or not. A disruption at the processing stage—whether deliberate, accidental, or caused by sudden regulatory change in a supplier country—can spread through supply chains. Currently, Europe does not have strong enough institutions to deal with this (Le Mouel & Poitiers, 2023). Europe cannot rely on domestic processing capacity, as it does not meaningfully exist, and building it would take years even under the most ambitious policy scenarios currently on the table (Giurco et al., 2019).

2.4 Rare Earth Elements: The Industrial Chokepoint

Among all three Critical Raw Materials (CRMs) discussed in this chapter, Rare Earth Elements (REEs) are the most complex, and even in some ways, the most instructive case of strategic dependency. Vulnerability related to the cobalt is rooted in the mining stage, a fragile state (DRC) that produces most of the global cobalt, and that single state can influence the entire supply chain. The vulnerability related to lithium is one step further in the chain, the refining and processing stage, where China has the dominant power for the capabilities to convert the mined resources into battery-grade materials. Rare earth elements are different from both cobalt and lithium because the dependency is not located at a specific point of supply chain. It includes the entire industrial system – from mining and processing stages to manufacturing and much of the expertise needed for the industry.

This distinction is critical analytically. When the dependency is concentrated at a specific stage, the policy responses can, in principle, target that stage. This includes building domestic refining capacity, diversifying mining sources, or developing recycling infrastructure. But when the dependency is about the entire supply chain, the measures and targeted response are alone insufficient to address and resolve the issues. Replicating China's position in rare earth elements—building a similar supply chain outside China—requires not only capital investment but decades of accumulated expertise, integrated industrial infrastructure, and the kind of policy coordination that has characterized China's approach to the sector since the 1980s (Tse, 2011; Wübbeke, 2013).

Another key difference between rare earth elements and the other two materials is that their strategic importance has already been tested in practice. China's dominance in all stages of the rare earth elements supply chain, along with the use of resources as a geopolitical tool—described as resource weaponization—is not merely theoretical; it has already been demonstrated in practice. A notable example is the 2010 China–Japan rare earth dispute, and a more recent one was the export restriction in response to US tariffs and broader geopolitical tensions. These examples show the high-level dependency of European industries on Chinese rare earth supply chains and showed both the leverage that supply concentration can create and the risks that arise when critical dependencies are spread across global value chains (Szczepański, 2025). To understand this dependency, it is important to know what rare earth elements (REEs) are, why they are vital for Europe's industrial and energy transition, and how China became a dominant power in this supply chain.

2.4.1 What Rare Earth Elements Are and Why They Matter for Europe

Rare earth elements (REEs) are a group of 17 metals, and despite their name, they are not particularly rare. They are found in deposits of several countries in the world, including China, Russia, the United States, Australia, and parts of Africa (Tse, 2011; USGS, 2017). REEs are strategically important not because they are geographically scarce, but because of the cost and difficulty of extracting and processing them into usable forms. The rare earth deposits often contain only small amounts of usable material, and separating the elements from each other needs complex chemical processes—which are also harmful for the environment. That is why commercial production is limited to a few locations in the world (Wübbeke, 2013). This gap between availability of the material in the ground and limited access is one of the main reasons why rare earth elements have become so strategically important in the global economy.

Among the REE group, three elements are more important for Europe’s energy transition: neodymium, dysprosium, and praseodymium. These are the key ingredients of neodymium-iron-boron (NdFeB) magnets[11], which are the most powerful type of permanent magnet available in the market. They are used in the generators of wind

[11] NdFeB magnets are the strongest commercially available permanent magnets. While neodymium provides the primary magnetic strength, heavy rare earth elements like dysprosium are added to increase the magnet's resistance to demagnetization at the high operating temperatures found in electric vehicle motors and wind turbines.

turbines and the traction motors of electric vehicles (Verma et al., 2022). When permanent magnets are used in a wind turbine, it becomes lighter, more reliable, and even suited better for offshore conditions. That is why they became a dominant technology for Europe aiming to expand its offshore wind capacity. For electric vehicles, permanent magnet motors provide higher efficiency and more power than other motor types, making it possible to produce smaller and lighter drivetrains (Czerwiński, 2022). Both technologies are central in the EU's decarbonization strategy, and both rely on these three elements that currently do not have a large-scale alternative. Although researchers are currently working on a magnet design to use less dysprosium or replace a part of neodymium with other materials; no alternative has yet been able to provide the level of performance needed for large-scale wind and electric vehicle technologies (Czerwiński, 2022; Verma et al., 2022).

According to senior European Commission officials, the EU consumes around 20,000 tons of permanent magnets per year. Between 17,000 and 18,000 tons of magnets come from China—meaning that roughly 85 to 90% of Europe's permanent magnet supply is imported from a single country (O'Carroll, 2026). More broadly, China provides around 98% of the EU's rare earth element supply, a dependency that covers the entire supply chain, from raw material extraction to the ready-to-use magnets for European wind turbines and electric vehicles (European Commission, 2020; Blondeel et al., 2021). As Europe expands its wind energy and electric vehicle sectors to meet Green Deal targets, demand for these materials will increase accordingly. The IEA projects that most of the future increase in demand for REEs until 2040 will come from clean energy technologies, with wind and EV applications driving the largest increases (IEA, 2021). For Europe, which produces almost none of these materials domestically, this will likely increase an already serious dependency rather than improve supply security.

2.4.2 China's Full-Chain Industrial Dominance

China's position in rare earth elements was not simply the result of geology. It emerged from a long-term industrial strategy in which extraction, processing, research, training, and downstream manufacturing were brought together into a coordinated system.

This is what makes rare earth dependency different from the other two cases discussed in this chapter. In the case of rare earth elements, China is not just a major producer. Over time, it became the country where the entire REE supply chain was organized, standardized, and developed through decades of state-led coordination and investment (Tse, 2011; Wübbeke, 2013; Vekasi, 2018). As shown in Figure 2.6, this strategy has resulted in China capturing the vast majority of global magnet manufacturing.

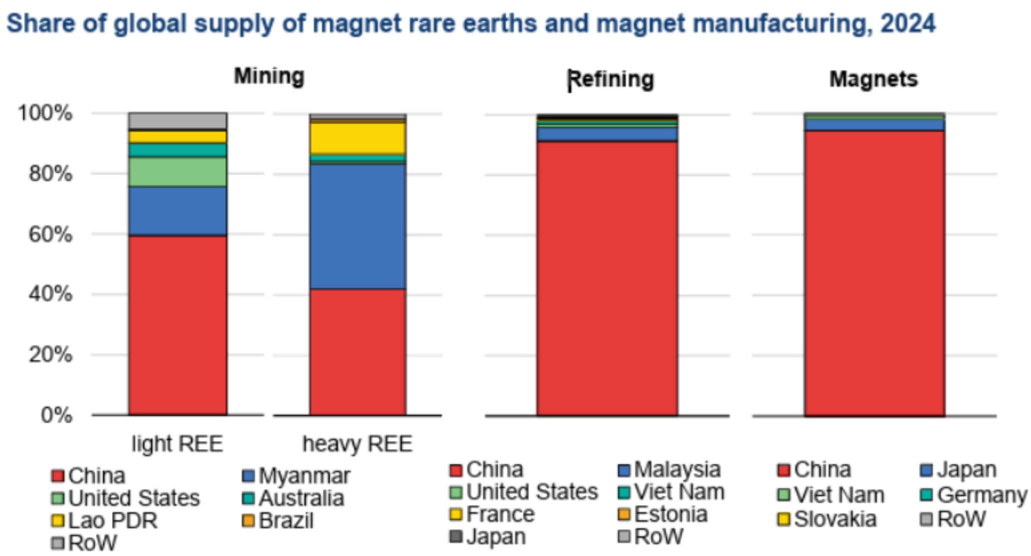

Figure 2.6. Share of global supply of rare-earth magnets and magnet manufacturing, 2024. Source: International Energy Agency (IEA), Rare Earth Elements: Pathways to Secure and Diversified Supply Chains (2026).

Notes: REE = rare earth element; RoW = rest of world. The figures refer only to magnet rare earths (neodymium, praseodymium, dysprosium, and terbium).

Before the 1990s, China's rare earth industry was highly fragmented, and there were small firms operating under weak and uneven regulation. But during the 1990s and 2000s, the state gradually put the sector under closer coordination and control. Export quotas, production limits, pricing policies, and industrial consolidation all played a role in this process. Over time, the industry was reorganized into a small number of large regional state-owned groups, which helped the government increase its control over production and prices while also reducing illegal mining (Vekasi, 2018). This is important because it shows that China's dominance did not emerge naturally from market forces alone. It was built this gradually through government policies that were designed to strengthen domestic industry rather than only relying on free-market competition. The rare earth market was therefore shaped not only by supply and demand but also by long-term state intervention (Mancheri et al., 2019; Wübbeke, 2013).

China built not only mines and factories but also the knowledge, skills, and institutional system needed for long-term industrial dominance in rare earths. Rare earth dominance depends on knowledge as much as on material access. The ability to separate, refine, and make them usable is not something that can happen overnight; it develops through long-term learning, accumulated expertise, and continuous technological refinement. Strategic industries did not enter into the market competition and were supported through a system that aligned industrial goals with state capacity. This created the conditions for the kind of sectoral coordination that rare earth processing required (Hsueh, 2011; Tse, 2011; Vekasi, 2018).

A further dimension of this dominance is the price. China could keep prices low enough to make the competition difficult for producers in other countries. Chinese pricing and export policy helped with keeping foreign producers out of the market and, at the same time, attracting investment and expertise into China through joint ventures, the relocation of downstream production, and deeper integration into global trade after China joined the World Trade Organization in 2001 (Klinger, 2017). This created a self-reinforcing structure: when prices are low, new mines in other countries struggle to stay profitable; when they are unprofitable, new competitors are not able to enter the market; and when alternative suppliers fail to compete, the dominant supplier keeps its advantage (Mancheri et al., 2019; Vekasi, 2018).

This is also where the rare earth case connects most clearly to the theoretical argument developed in Chapter 1. Countries that control the key parts of a global supply chain gain structural power because other countries depend on that dominant power to get access to the system (Farrell & Newman, 2019). China's dominance in processing, refining, and magnet manufacturing places it at the center of the rare earth supply chain. This does not mean China will always use that position coercively, but it does mean that distribution of power within the network is not equal. Europe depends on a system whose most important stages are controlled outside Europe, and this asymmetry moves economic interdependence into strategic vulnerability (Keohane & Nye, 1989; Farrell & Newman, 2019).

This challenge cannot be overcome simply by opening new mines or signing new supply agreements. For Europe, the problem is not just a lack of ore; it is lack of a wider industrial ecosystem needed to process and use rare earths. Building that ecosystem requires time, state coordination, skilled labor, and sustained long-term investment. Europe closed much of its mining and processing industry in the 1970s and 1980s as imports became cheaper and domestic production became less competitive. This created disadvantages that are now very difficult to reverse (O'Carroll, 2026). In other words, Europe would need to build in years what China spent decades developing, particularly in the sector of REEs. Seen this way, China's full-chain dominance is the clearest example in this chapter of a dependency that is not located at a single point but distributed across the whole industrial system— And this is what makes the rare earth case structurally more difficult to overcome than the vulnerabilities examined in the cobalt and lithium sections.

2.4.3 Resource Weaponization: The 2010 Episode and Its Implications

China's consolidation of the entire rare earth value chain also paved the ground to use market dominance as a geopolitical leverage. In international relations scholarship, this concept is often called weaponized interdependence: the idea that states controlling the central parts of global economic networks can use that position to exert pressure on dependent actors (Farrell & Newman, 2019). In the rare earth sector, China's dominance in midstream processing creates exactly this kind of structural chokepoint (Humphries, 2013). Asymmetric dependency gives the dominant supplier the ability to threaten supply disruptions in order to gain political concessions (Tse, 2011; Wübbeke, 2013). The clean energy transition increases this vulnerability even more because wind turbines and electric vehicles rely heavily on permanent magnets made from elements such as dysprosium and neodymium. Countries that depend on them become more exposed to China's leverage as demand for these technologies grows (Alonso et al., 2012; O'Sullivan et al., 2017).

This leverage became visible in September 2010, and rare earth elements were brought into the public eye as a tool of economic statecraft. A collision near the disputed Senkaku/Diaoyu Islands between a Chinese fishing trawler and Japanese Coast Guard vessels led to a diplomatic crisis. After Japan's arrest of the Chinese captain, Japanese importers reported that they were unable to import rare earth elements from Chinese ports. Chinese authorities consistently denied any ban, but a Japanese government survey of 152 firms found that every company trading in rare earths reported some form of restrictions and difficulties—from new procedures at the export license stage to shipments being stopped at customs (Vekasi, 2018). At that time, Japan was the world's largest importer of rare earths and was heavily dependent on China for its electronics, automotive, and environmental technology industries (Humphries, 2013; Mancheri & Marukawa, 2016).

In the short term, the case showed the real risks that can be created by supply chain concentration. Prices for critical rare earth elements increased rapidly within a few months, as markets reacted to fears of a prolonged supply disruption (Mancheri et al., 2019; Sprecher et al., 2015). Within a few weeks, Japan released the detained captain since the pressure on manufacturing industries was increasing. This move was widely considered a response to disruption and political pressure. (Blackwill & Harris, 2016; Vekasi, 2018).

However, a wider look at this episode tells a more complicated story. The weaponization of rare earth supplies caused a backlash that at the end worked against China's longer-term interests. By making the dependency visible, China unintentionally turned rare earths into a national security issue for advanced industrial economies. It accelerated the diversification efforts China wanted to prevent (Mancheri et al., 2019; Vekasi, 2018). The price rise made the unviable non-Chinese mining projects financially attractive, and the countries that had paid little attention to rare earth supply chains suddenly had strong political reasons to act.

The international system responded through two main channels. On the legal side, the United States, the European Union, and Japan brought a joint case against China at the WTO. They argued that China's export quotas and tariffs on rare earths violated the international trade rules (Humphries, 2013; Mancheri et al., 2019). In 2014, the WTO ruled against China, finding that the export restrictions were inconsistent with trade law because China had not imposed similar restrictions on domestic production and consumption. As a result, China was required to remove its official export quota system by 2015 (Mancheri et al., 2019; Vekasi, 2018).

At the same time, targeted countries started reducing their structural dependency on China. The Japanese government announced a policy called "pluralistic risk management"—investing around 42 billion yen in subsidies through the Ministry of Economy, Trade and Industry (METI) to help firms reduce rare earth consumption, develop substitutes, and advance recycling (Vekasi, 2018). State-backed institutions like Japan Organization for Metals and Energy Security (JOGMEC) started partnerships with private companies to build alternative supply networks in Asia, the Americas, and Australia. The partnership aimed to accelerate the development of REEs projects like Mountain Pass in the United States and Mount Weld in Australia (Humphries, 2013; Golev et al., 2014; Mancheri & Marukawa, 2016). By the late 2010s, Japan reduced importing rare earth elements from China from over 90% to around 60%. It was a significant shift, even if full independence remained out of reach (Vekasi, 2018).

Coercive leverage over supply chains is real, but it is not unlimited. Research on economic statecraft has shown that dependent actors can adapt when the stakes stay high—and the more visible the coercion, the stronger the political motivation to diversify (Gholz & Hughes, 2021). China's 2010 actions demonstrated its capacity to cause disruption, but it was also demonstrated that the capacity has limits when the target is large enough and motivated enough to respond.

After recognizing these limits, China shifted its approach. Rather than relying on export quotas that can be easily challenged by the WTO, it has moved toward more targeted and legally ambiguous mechanisms. The mechanism includes strict export licensing requirements on strategic minerals and bans on the export of rare earth processing and separation technologies (Vigna, 2023; Reuters, 2023). In April 2025, in retaliation for US tariffs, China imposed global export restrictions on rare earths that also hit Europe's automotive sector directly and there were threats on further restrictions before a temporary truce was agreed later that year (O'Carroll, 2026). China is shifting its control towards processing technology, industrial expertise, and intellectual property and this way it can keep the leverage without creating the kind of major market disruption that pushed other countries to diversify rapidly after 2010.

These dynamics are not limited to rare earths. Europe’s earlier dependence on Russian natural gas followed a similar pattern, where the use of weaponization caused immediate pressure but also accelerated diversification efforts, including initiatives such as REPowerEU—something that ultimately did not work in Russia's favor (LaBelle, 2023). These examples show how resource concentration can become a geopolitical instrument—demonstrating both the real costs of structural dependency and the limits of coercive leverage when dependent actors are willing and able to respond.

2.4.4 Europe's Strategic Exposure

Europe’s vulnerability to rare earth supply disruptions is not limited to a few specialized companies. It covers many of the important manufacturing sectors on the continent. According to network analysis by the European Central Bank (ECB), more than 80% of large companies operating in eurozone countries are connected, directly or indirectly, to a Chinese rare earth producer through a few numbers of supply-chain links. This shows that dependency is widespread and not limited to a small number of sectors inside Europe (Banin et al., 2025). The wind energy sectors is one of the most vulnerable sectors because offshore wind turbines depend heavily on permanent magnets made with neodymium and dysprosium, while Europe is planning a major expansion of offshore wind under the Green Deal (Teer, 2025; European Commission, 2020). The automotive sector faces a similar vulnerability. As electric vehicles become widespread, permanent magnet motors have become the industry standard, and this makes rare earth elements difficult to replace in vehicle drivetrains (Carrara et al., 2020). Defense and aerospace are also affected. Rare earth elements are used in radar systems, missile guidance, fighter jet components, and many types of dual-use electronics. It means that supply disruptions can create security risks that are more than industrial inconvenience (Teer, 2025; Rabe et al., 2017). Because these materials are used in several industries and supply chains at the same time, even partial disruptions can create wider challenges throughout all sectors (Gholz & Hughes, 2021).

In September 2025, Beijing had approved only 19 out of 141 EU rare earth license requests and left European manufacturers with very limited access to REEs, a material that Europe had few alternative sources for. The production lines were affected immediately. China's rare earth restrictions alone caused seven production stoppages in August 2025, and industry associations warned that another 46 could occur in September if supply shortages persisted (Teer, 2025). Prices also increased as inventories began to run out and panic spread through supply chains that had depended on uninterrupted Chinese supply for a long time. This case exposed a vulnerability that had already been visible in supply-chain data but was not taken seriously by politicians until disruptions started affecting industrial production directly. Furthermore, the case illustrates that even limited export restrictions can have serious effects on European industry (Banin et al., 2025). African CRMs exports to the EU, which are totally only €1.25 billion in 2024 compared to €16.6 billion for China, show how far Europe is from having a credible alternative sourcing base (Marangio, 2026).

Building domestic alternatives in order to reduce this dependency is structurally difficult. The biggest barrier is the lack of rare earth separation and refining capacity in Europe. The LKAB deposit in Kiruna, Sweden—the largest known rare earth deposit in Europe—is considered the most advanced domestic alternative, but the process to turn it into a commercial production takes more than a decade. It means it cannot solve current supply pressures (O'Carroll, 2026).

Substitution also cannot offer an immediate solution. Designing wind turbines or electric vehicle motors without rare earth permanent magnets makes the equipment heavier, larger, and less efficient. In addition, alternative technologies still do not perform at level that Europe needs (Pavel et al., 2017; Smith Stegen, 2015). Despite ongoing research, no rare-earth-free magnet technology could have reached the level needed to replace NdFeB magnets in high-demand applications (Carrara et al., 2020; Wübbeke, 2013).

Therefore, rare earth elements (REEs) are the most complex and even in some ways the most instructive case of strategic dependency. Unlike cobalt or lithium, the problem is not limited to a single stage of the supply chain, and it covers broader industrial systems where Europe does not have capacity in processing, refining, separation, and magnet manufacturing (Garcia-Herrero & Rühlig, 2026; IEA, 2021). As a result, the challenge cannot be solved by just opening one mine, building one refinery, or signing new supply agreements. Reducing dependency needs rebuilding industrial capacities that Europe stopped during the 1980s and 1990s (European Commission, 2020). China's willingness to use its position as a geopolitical tool, especially in 2010 and again in 2025, means that the cost of inaction is more than just economic, as it can be strategic (Garcia-Herrero & Rühlig, 2026; Teer, 2025). The way Europe responds to the dependency, and whether its current policies are sufficient, will be examined in Chapter 3.

Chapter III

Analysis of the European Union's Critical Raw Materials Strategy

This chapter analyses the European Union's response to the materials security dilemma created by its dependence on critical raw materials. It examines the policy shift that led the European Union to treat critical raw materials as a strategic issue, with particular attention to the emergence of open strategic autonomy and the adoption of the Critical Raw Materials Act (CRMA). The chapter then evaluates the main policy instruments introduced by the CRMA, assesses its strengths and structural limitations, and compares the European approach with the strategies adopted by other major powers, including the United States, China, and Japan. Through this analysis, the chapter assesses whether the European Union's current framework is capable of reducing strategic dependencies and strengthening the resilience of its critical raw material supply chains.

3.1 The Evolution of the EU's Critical Raw Materials Strategy

Historically, the European Union tried to secure raw materials through the logic of global market integration and international trade, meaning that integration was perceived as an automatic solution to challenges related to supply chain. That said, the EU focused more on market harmonization and competition enforcement, rather than directly controlling where the materials came from (Ivančík & Dušek, 2026). In reality, the responsibility for securing industrial input was left to private companies and the dynamics of the free markets, an approach based on a belief that global market could provide raw material in a reliable, sustainable and affordable way by itself. However, the disruptions and crises of the past decade, including the COVID-19 pandemic, the Russian invasion of Ukraine, and broader supply-chain and energy crises, revealed the weaknesses of this approach. In addition to the crises, the transition from fossil fuels to a mineral-intensive green energy system pushed Europe to rethink its strategy and consider critical raw materials not simply as ordinary economic goods, but a strategic and geopolitical asset for Europe's economic security, resilience, and strategic autonomy (Fomina, 2023).

The main factor that led to this political awakening was the European Green Deal in 2019.[12] The Green Deal was more than just an environmental policy and was considered the European Union's new strategy for economic growth and modernization. This policy aimed to build a climate-neutral and digitalized economy by 2050. But soon it became clear that achieving these goals requires rapid expansion of green technologies on a large scale. Electric vehicles, batteries, solar panels, and wind turbines rely on critical raw materials (European Commission, 2020). As a result, European policymakers realized that the green transition was not really removing the dependency of Europe on external resources, but a shift from one type of dependency (fossil fuels) to another type of dependency (CRMs).

At the same time as the increase in domestic demand, several events, including the Covid-19 pandemic, caused major disruptions in global supply chains. The pandemic revealed the fragility of global production networks as lockdowns, border restrictions, and logistical disruptions interrupted the flow of goods across international supply chains (Trade Policy Review, 2021). After the pandemic, another crisis caused by the Russian invasion of Ukraine revealed the risk of overwhelming reliance on external suppliers for critical resources. In addition, the 2026 conflict involving Iran, Israel, and United States of America resulted in near-total blockade of the Strait of Hormuz and exposed the vulnerability of global maritime chokepoints – especially with some critical raw materials and strategic commodities, including aluminium, helium, and fertilisers (Hinz et al., 2026; Osei-Dwomoh et al., 2026; Roland Berger, 2026). Together, these crises pushed the European Union to rethink its management of external economic and geopolitical risks, particularly forms of dependency that can be used as geopolitical tools (Alcidi et al., 2023; Mouel, 2023).

The geopolitical tensions and environmental ambitions were high enough to make Europe treat critical raw materials as a security issue, and afterwards the minerals started

[12] Introduced in 2019, the European Green Deal is a set of policy initiatives by the European Commission with the overarching aim of making the European Union climate neutral by 2050, decoupling economic growth from resource use, and transitioning to a circular economy.

to be considered an asset which is connected to geopolitical influence, economic stability, and even defense capabilities (Fomina, 2023). The European Union then gradually redefined industrial competitiveness and included resilience as an important objective to be able to resist external shocks, manage risks, and maintain access to essential technologies (Trade Policy Review, 2021). In this context, the economic policy became a strategic tool to reduce vulnerabilities that the free market failed to address (Ivančík & Dušek, 2026).

The concept of "strategic autonomy," which was traditionally associated with the areas of defense and foreign policy, expanded to include European industrial and trade discussions as a significant element. But at the same time, the European Union recognized that complete self-sufficiency in critical raw materials is not realistic, neither geographically nor economically. Therefore, the EU developed a concept named Open Strategic Autonomy (OSA) (Trade Policy Review, 2021). This approach has two objectives: maintaining commitment to global trade and international cooperation and protecting European interests against unfair practices, geopolitical pressure, and supply-chain disruptions (Alcidi et al., 2023).

Through the concept of open strategic autonomy, the European Union wanted to stay connected and competitive in the global economy and, at the same time, reduce its excessive dependency on big powers such as China. This way, the EU could make independent economic and political decisions based on its own interests and values (Trade Policy Review, 2021). Regarding the issues related to the critical raw materials, this framework had two strategies: diversifying imports to prevent overdependence on one single supplier and strengthening domestic capacities in extraction, refining, and recycling (Hool et al., 2024). This approach was stronger because it combined market integration with public intervention and industrial planning (Ivančík & Dušek, 2026).

The idea of open strategic autonomy influenced the direction of EU policymaking and led to more legislative intervention in the raw materials sector. Before this shift, the European Union had a framework called the Raw Materials Initiative, introduced in 2008, which focused on voluntary measures, risk assessments, and general support for Research and Development (R&D). However, this framework could not reduce Europe's dependency because importing raw materials was the cheapest and most attractive option for private companies (Hool et al., 2024). Moreover, the structure of mineral supply chains is complex, and the ability of market mechanisms to diversify supply quickly enough to meet the demands by Green Deal was limited (Global Critical Minerals Outlook, 2025).

The more Europe recognized its vulnerability in critical raw materials, the more the European Union was pushed to move beyond its traditional regulatory approach. European policymakers came to the conclusion that a stronger legislative framework was needed to guide industrial activity and coordinate public and private investments. This policy thinking eventually led to the creation of the Critical Raw Materials Act (CRMA) in 2024, which was the European Union's first major step toward securing critical raw material supply chains through binding industrial policy (Hool et al., 2024).

One of the main characteristics of the CRMA was its practical approach. It became the practical implementation of open strategic autonomy. The European Union started to directly intervene in order to reduce supply risks in critical raw materials. The CRMA enabled the EU to classify specific raw materials as "critical" or "strategic" based on their economic importance and future demand, and this allowed policymakers to prioritize industrial support related to these materials (Regulation (EU) 2024/1252). Furthermore, the policy aimed to strengthen Europe's domestic capacities in extraction, processing, and recycling, and at the same time, reduce excessive dependency of Europe on any single external supplier (Hool et al., 2024).

In addition, the European Union combined its environmental goals with its economic security objectives. The strategy linked supply-chain security to sustainability and emphasized that resilient mineral supply chains should also follow environmental, social, and governance (ESG) standards (Fomina, 2023). In this way, the EU aimed to support the environmental goals of the Green Deal, and also make materials that are produced according to European environmental and social standards more attractive and competitive in international markets.

3.2 The Critical Raw Materials Act: Objectives and Policy Instruments

The Critical Raw Materials Act (Regulation (EU) 2024/1252, 2024) came into force in May 2024 and created a comprehensive legislative framework with the aim to help the European Union secure the supply of raw materials that are essential for the European economy, and to accelerate green and digital transitions. The CRMA classifies materials into two categories: “critical” raw materials (CRMs) and “strategic” raw materials (SRMs). The CRMA defines critical raw materials as materials that have high economic importance to the European Union and at the same time have a high risk of supply disruption. Strategic raw materials are a subset of critical raw materials that are considered essential for strategic technologies, such as renewable energy, digital technologies, aerospace, and defence, and for which future demand is expected to grow significantly (Regulation (EU) 2024/1252). This distinction is important because it determines which policy instruments, regulatory measures, and support mechanisms apply to different materials in the supply chain.

The determination of whether a raw material is critical is based on a quantitative assessment of two main factors: its economic importance and its supply risk. Economic importance refers to the level of essentiality of materials for European industries. It is assessed based on the importance of the industries that rely on it and if the material can easily and cheaply be replaced by alternative materials (Regulation (EU) 2024/1252). However, supply risk evaluates the vulnerability of the European Union to disruptions in the supply chain. This evaluation includes factors such as the concentration of production in a few countries, the EU's dependency on imports at all stages of the supply chain, and the political and governance situation in supplier states (Ragonnaud, 2024).

The CRMA identifies thirty-four critical raw materials and seventeen of them are classified as strategic raw materials. These materials are considered indispensable for strategic technologies including renewable energy production, digital infrastructure, and the aerospace and defense sectors. For a material to be considered “strategic,” two additional conditions must exist: it must be expected to experience a rapid increase in demand that exceed the available supply and quick expansion in its global production should be difficult (Regulation (EU) 2024/1252). Figure 3.1 outlines the specific materials that currently meet these criteria under the CRMA.

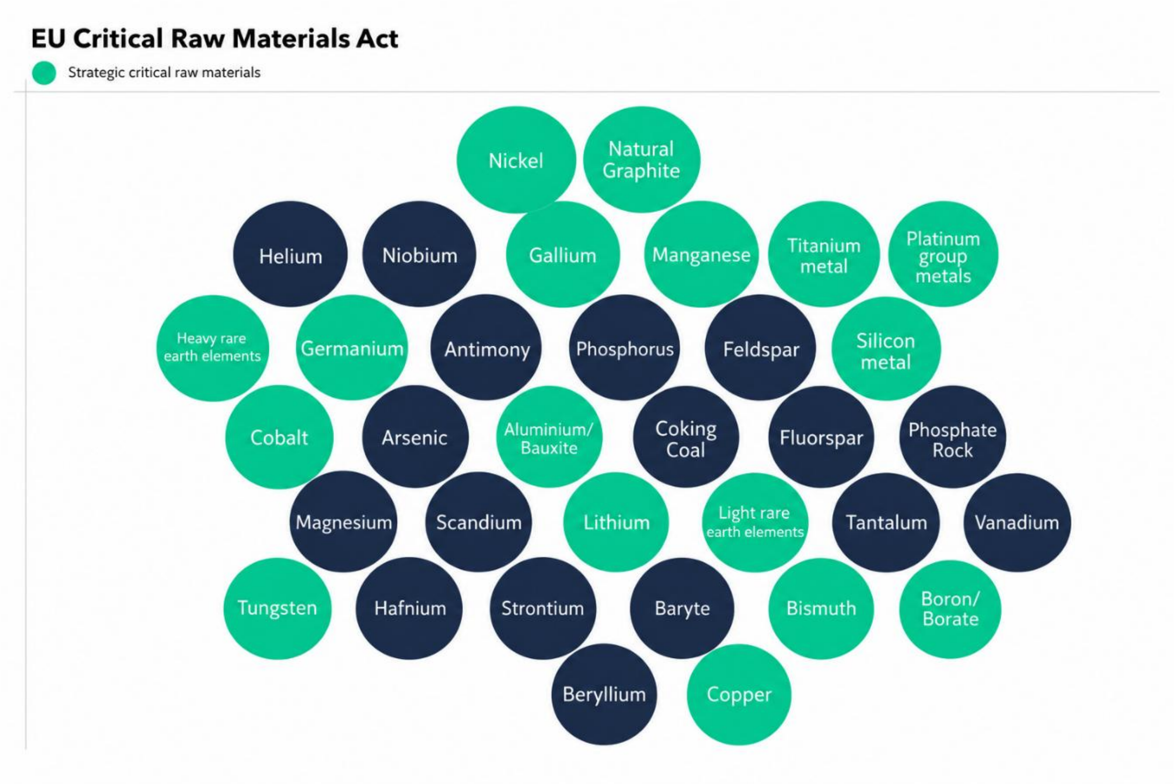

Figure 3.1. Critical and Strategic Raw Materials under the Critical Raw Materials Act (CRMA). Source: Adapted from ChainTraced (2024).

To reach the objective of supply chain resilience, the CRMA introduces four non-binding benchmarks to be achieved by 2030 at the European Union level. These targets are based on percentages of the EU's annual consumption of strategic raw materials and aim to reduce dependency on external suppliers by increasing domestic capacity. According to the framework, the following targets should be achieved by 2030:

1. Domestic extraction should cover at least 10% of annual consumption;
2. Processing capacity should reach at least 40%;
3. Domestic recycling should reach at least 25%;
4. "By 2030, the Union is not dependent on a single third country for more than 65% of its supply of any strategic raw material, unprocessed and at any stage of processing." (Regulation (EU) 2024/1252).

The logic behind these specific benchmarks is related to different stages of vulnerabilities in the supply chain. For example, the 40% processing target to expand the refining capacity of Europe addresses the processing stage. This stage is often linked to materials such as lithium, where the downstream automotive industries are dependent on the midstream stage (processing bottleneck) located abroad (Bucciarelli & d'Herbemont, 2025). Similarly, the 65% diversification limit is intended to reduce the risks related to extreme geographic concentration, an issue visible in the cobalt case (Buysse & Essers, 2023).

The European Union uses a policy instrument called “Strategic Projects" to achieve its capacity benchmarks. “Strategic Project" is a legal status given to extraction, processing, or recycling projects that are expected to contribute to the security of the European supply chain. The criteria to obtain the label are:

1. The project must demonstrate that it is technically feasible with credible production expectations;
2. The project must provide benefits for the European market;
3. The project must comply with environmental and social sustainability standards (Regulation (EU) 2024/1252)

Once a project receives the Strategic Project designation, this status provides faster permitting procedures, easier access to financing, and greater political and administrative support.

Historically, long administrative procedures and complicated regulations have always slowed down the development of new mining and refining investments in Europe. To resolve this, the Critical Raw Materials Act forces member states to accelerate the permit-granting process. The permitting decision should be legally made in twenty-seven months for extraction projects and fifteen months for processing and recycling projects (Ragonnaud, 2024). To facilitate this coordination, Member States are required to designate single points of contact that serve as the sole interlocutor for project promoters, managing all necessary environmental assessments and administrative authorizations through a bundled and centralized procedure (Regulation (EU) 2024/1252). Furthermore, member state must create single points of contact to simplify coordination for project developers. These offices are responsible for managing environmental assessments and administrative procedures (Regulation (EU) 2024/1252).

Normally, environmental laws like the EU's Water Framework Directive (WFD) or Habitats Directive (HD)[13] can completely stop a mining or refining project if it risks harming local nature or water sources. To give legal justification for strategic projects, the CRMA gives Strategic Projects a legal status called "overriding public interest", through which the projects can gain permission to obtain approval even if they conflict with environmental laws—provided that no alternative locations exist (Regulation (EU) 2024/1252). This way, private investors have certainty on their plans and can invest high level of capital, which is required for such complex extraction and refining projects.

The CRMA establishes these regulations to accelerate project development, but it does not create a dedicated EU-level fund specifically for its implementation. Instead, projects have to use the public and private funds that already exist. In addition, the European Commission and member states are tasked with introducing project developers to major lenders, such as the European Investment Bank (EIB) or national development banks, for financial support (European Commission, 2025). By this coordination, the EU makes the project safer and more organized as project developers can secure their funds this way.

To monitor and manage the policy instruments and to make sure the Member States and institutions apply the rules in a coordinated and consistent way, the CRMA creates an organized institutional system centered around the European Critical Raw Materials Board. The Board is composed of high-level officials, each representing a member state, and its regular meetings are chaired by the European Commission. The Board's mandate is to coordinate raw material policies across the internal market instead of each member state acting independently in different ways (European Commission, 2024). There are specialized subgroups inside the Board, each focusing on specific issues such as exploration, financing, circularity, and strategic stockpiling.

One of the key functions of this governance structure is the constant monitoring of supply chain risks. The European Commission and the Board are tasked with tracking trade flows, price volatility, market concentration, and potential bottlenecks. The EU

[13] The Water Framework Directive (2000) aims to protect and restore clean water across Europe, while the Habitats Directive (1992) ensures the conservation of rare and threatened species and their natural habitats. Together, they form the cornerstone of the EU’s strict nature conservation policy.

seeks to carefully assess the vulnerabilities to disruptions such as geopolitical conflicts (e.g., a war affecting European industrial production) and logistical failures (e.g., the blockage of major shipping routes). To reach this objective, the framework introduces mandatory simulation-based stress tests on strategic raw material supply chains that must be conducted at least once every three years (Ragonnaud, 2024).

This risk monitoring framework also imposes direct obligations on the private sector. Large companies that manufacture strategic technologies (including electric vehicle batteries, renewable energy generators, and aerospace equipment) are legally required to conduct regular risk assessments of their own raw material supply chains to find and resolve their weaknesses. In addition, companies are required to trace the geographic origins of their materials and evaluate their specific vulnerabilities related to potential disruptions within that supply chain (Regulation (EU) 2024/1252). To better manage these market risks, the CRMA establishes a joint purchasing system. This mechanism allows the European Commission to aggregate demand by grouping the orders of European companies into one collective order; this way, instead of each company sourcing materials independently, the European Commission can seek unified offers from global suppliers. By putting all these orders together, the system gives European companies much stronger bargaining power to get better prices and more stable, long-term contracts. This is especially helpful when dealing with markets that are controlled by only a few massive global suppliers. (Ragonnaud, 2024).

Considering that Europe has geological limitations (lack of enough natural underground deposits of raw materials) the focus should be on a circular economy, which means recycling and reusing the already existing materials. Increasing the secondary supply (recycled raw materials) is vital for the long-term resilience of Europe. That is why the member states are required to build better domestic systems to collect, sort, and process waste streams (e.g., old electronics, batteries) that contain critical raw materials (Regulation (EU) 2024/1252). In addition, the EU seeks to unlock the potential of anthropogenic deposits[14]. Operators of both active and closed extractive waste facilities

[14] Anthropogenic deposits refer to secondary, human-made concentrations of minerals, such as historical mining waste, tailings, or industrial landfills, which can be re-processed to extract leftover critical raw materials using modern technologies.

are required to conduct economic assessments to evaluate whether it is technically possible and financially worth it to extract leftover materials from mining waste.

Furthermore, under the recycling rules, the EU is establishing strict requirements for permanent magnets, which are placed at the heart of green technologies, as they are essential components for manufacturing vehicle motors, industrial robots, and wind turbines. Any natural or legal person that places a product containing permanent magnets on the European market must make sure the products are labeled clearly and have a digital data carrier. These data carriers must specify the exact chemical composition of the magnets, specifically the presence of rare earth elements such as neodymium, dysprosium, or praseodymium, which are highly valuable and hard-to-find (Regulation (EU) 2024/1252). This strict requirement facilitates the safe removal and recycling of magnets when the product's life ends. The recovery of these materials will pave the way for the EU to introduce a mandatory minimum amount of recycled materials for manufacturing new technologies. As a result, by legally forcing companies to use recycled materials, a secondary market for rare earth elements will be created within Europe (Cortina et al., 2026).

Finally, the CRMA requires member states to develop national exploration programs to support the long-term expansion of primary supply. The countries are required to use advanced technologies (including geoscientific surveys, geochemical campaigns, and mineral mapping) to keep the geological data updated across the continent. By gathering this important data and publishing it, the framework aims to encourage future private investment by providing the initial data necessary to launch domestic extraction projects.

3.3 Strengths of the CRMA

The CRMA presents a serious policy response to the vulnerabilities created by the global energy transition. One of the important strengths of the CRMA is its accurate identification of the new materials security dilemma. It acknowledges that the energy transition does not make Europe fully independent; instead, it is a dependency shift from fossil fuels to critical raw materials. In addition, it recognizes that an imbalance in the supply chain (where one country controls the supply of a material) can be leveraged for state coercion (Farrell & Newman, 2019). Considering these geopolitical and security concerns, the EU no longer considers critical raw materials as ordinary economic goods, but rather as strategic assets that are vital for both economic stability and political influence. Crucially, the goals under the CRMA are not unrealistically designed to reach full self-sufficiency. European policymakers know that complete geological and economic independence in critical raw materials is impossible. This way of thinking makes the strategy of managed interdependence and resilience more realistic (Le Mouel & Poitiers, 2023). This way, Europe can build domestic capabilities where vulnerabilities are higher and, at the same time, benefit from the economic efficiencies provided by global trade.

A major strength of the CRMA is its recognition that vulnerability does not necessarily come from resource scarcity alone but emerges mainly by concentrated industrial chokepoints. Moreover, the framework targets the entire supply chain, which is very significant because it reflects a broader understanding that dependencies can extend beyond the mining and extraction phases. The lithium supply chain is a great example of this. The main risk for European automotive industries that rely on lithium is not a lack of the material; the risk is the extreme reliance on external actors (such as China) for the complex chemical refining needed to turn raw lithium into battery-grade material (Righetti & Rizos, 2023). That is why the framework attempts to build resilience exactly at the middle part of the chain (known as the midstream) by focusing on building processing and refining factories inside Europe. This shows the EU is taking serious and real actions instead of relying on mere political speeches. For example, in early 2025, the European Commission officially approved 47 strategic projects, including a large number of processing and recycling factories designed to bypass these exact foreign bottlenecks (Payne, 2025).

The CRMA has a clear understanding of the risks related to its external dimension. It recognizes that extreme geographic and institutional concentration is dangerous, especially when it comes to relying on a single country. If that one country experiences a political crisis, a war, or even just logistical failures, European industries are severely affected. Cobalt is a perfect example to show this risk, where the Democratic Republic of the Congo hosts a massive concentration of production, and almost all of the mined cobalt is then sent to China for refining. This creates severe governance and supply chain vulnerabilities (Bille, 2025). In order to solve this, the CRMA attempts to break this dangerous trap (the "instability nexus") by forcing companies to diversify imports and promote strategic partnerships with a variety of different countries instead of just one or a few. This way, Europe will face fewer threats in the case of any supply chain disruption. Furthermore, rather than attempting to isolate the European market, the EU knows it must be present in the global market. To spread out the risk, the CRMA uses initiatives like the Global Gateway[15] (the EU's international infrastructure fund) to invest in projects abroad. One example is the EU's financial backing for the Lobito Corridor, which is a major railway in Africa that connects inland mines directly to the Atlantic Ocean. By funding projects like this, Europe secures alternative and direct supply routes, so the minerals do not have to pass through China first. In exchange for these investments, the EU requires its new foreign partners to adopt much higher environmental and social standards (Bille, 2025; Defard & Voïta, 2024).

Furthermore, in addition to attempts to secure access to raw materials, the framework aims to improve domestic industrial and technological capacity. The CRMA recognizes that long-term supply chain resilience requires retaining actual manufacturing expertise and technological knowledge inside Europe's borders. This is relevant to the case of rare earth elements and their complexities. External dominance in rare earths is not just a result of geological endowment; instead, it comes from accumulated industrial expertise and technological control over the processing stages of the supply chain, such as the production of permanent magnets (Gholz & Hughes, 2021). Historically, Europe lacked specific processing and refining capabilities, and to address this, the CRMA is strongly pushing for the creation of secondary markets (markets for recycled materials) and setting strict goals for building recycling factories. By doing this, the policy targets the precise industrial nodes where European industry has struggled the most. This strategy has already started to show real-world results. Private companies in France and Estonia building capabilities for rare earth separation and magnet manufacturing are examples that prove the CRMA's strategy of re-internalization (bringing these complex

[15] Launched in 2021, the Global Gateway is widely considered the EU’s strategic alternative to China’s Belt and Road Initiative (BRI). The Lobito Corridor specifically connects the resource-rich regions of the DRC and Zambia to the Angolan coast, deliberately bypassing Chinese-dominated logistical routes.

manufacturing processes back to Europe) is working (Onstad, 2024; Jakimów et al., 2024).

Beyond physical solutions like building mines and recycling plants, the CRMA introduces important institutional innovations (new organizational and administrative tools) that provide an extra layer of strategic resilience. In the past, European countries reacted to crises individually, which often led to vulnerable and fragmented national responses. To solve this, the policy creates shared mechanisms to cover all the member states, such as centralized supply-chain monitoring dashboards, coordinated stress tests, and a joint purchasing system. This way, the framework makes the European Union a unified industrial bloc (a single massive economic group working together). This allows Europe to use its collective market power to secure more procurement contracts and anticipate global disruptions before they can affect European industries (Ragonnaud, 2024).

Finally, the Critical Raw Materials Act is not a magic solution for fixing the European Union's deep dependency issues, nor does it completely remove the risks of global mineral procurement. But its true strength is that it looks at the entire picture and correctly identifies exactly where Europe's weaknesses are. By combining domestic capacity-building—such as building local refining and recycling factories—with international diversification (finding new global trading partners) and institutional coordination (all EU member states working together), the policy is considered the EU's first serious and organized effort to navigate the complex geopolitics of the green energy transition and fix its supply chain weaknesses in practice.

3.4 Structural Limitations of the CRMA

Several important structural weaknesses are revealed when testing CRMA against vulnerabilities generated by the energy transition. Indeed, the CRMA's 2030 targets for extraction, processing, and recycling show that the EU has a serious political ambition to strengthen and re-shore (bring back home) industrial capacity, but there are some constraints that make these objectives hard to achieve: geological scarcity, high economic costs, and long project-development timelines. Even if the domestic goals are achieved, it is expected that Europe will still be heavily dependent on Strategic Raw Materials

(SRMs) imports (around 65%) from non-EU countries. This means that external dependency will persist, as the CRMA was not originally designed to achieve full self-sufficiency (Tröster et al., 2024). Numerical benchmarks are not enough to resolve the supply-chain bottlenecks and geopolitical power imbalances, which are fundamental parts of the mineral market (Hool et al., 2023). In addition, the methodology behind these benchmarks lacks a strong justification because it is based on outdated trade statistics and insufficient transparency in the supply chain. In many cases, the final exporting country is clear, but Europe cannot always fully trace where raw materials are refined, processed, or incorporated into intermediate components before entering the European market (European Court of Auditors, 2026). This makes the EU's assessment of dependency and vulnerabilities even more complicated.

A central mechanism of the CRMA is to increase domestic mining by introducing Strategic Projects (a special government support to fast-track development) which are supposed to accelerate the process of obtaining permits. This means that if a project is considered strategic, the permit will be granted within 27 months. However, the administrative procedure timeline is a small part of the problem related to the supply chain and solving it does not create a big difference. In reality, building a new mine takes a long time and involves a complex process. A mining project, from geological discovery and technical studies to commercial production, takes averagely more than fifteen years (European Court of Auditors, 2026).

In addition to the temporal and economic limitations of Europe, the expansion of domestic mining extraction faces important social and environmental challenges. The expansion of mining activities can harm local and indigenous communities and also conflict with environmental protection objectives. Several important mineral deposits are located in ecologically sensitive areas or indigenous territories. The lands of the Sámi people[16] in northern Europe are a good example, where mining projects and building related infrastructure can threaten reindeer herding, grazing lands, local ecosystems, and traditional livelihoods that are vital for Sámi culture and identity. Therefore, the EU's pursuit of strategic autonomy in raw materials creates a conflict between supply security,

[16] The Sámi are the only officially recognized Indigenous people within the European Union. Their traditional territory, Sápmi, stretches across the northern parts of Sweden, Finland, Norway, and Russia, a region that overlaps significantly with Europe's largest known critical mineral deposits.

environmental sustainability, and the protection of local and indigenous rights (Bogojević, 2024). Speeding up mining permits can affect the Environmental Impact Assessment (EIA)[17] and the public consultation period. Giving local communities less time to evaluate and respond to projects may affect the accuracy and comprehensiveness of the assessment and, at the same time, may foster stronger local opposition. Communities may respond through legal challenges, political mobilization, or protests even after the project obtains the permit (Tröster et al., 2024). Therefore, the acceleration of administrative procedures is less likely to resolve the conflict between the growing demand for domestic extraction and environmental and social protections (Correia & Falck, 2025). In this sense, the challenge the European Union faces is not only geopolitical, but also socio-political and institutional, as the pursuit of strategic autonomy can conflict with domestic environmental governance and public acceptance (Le Mouel & Poitiers, 2023; Paleari, 2024).

Prioritizing domestic extraction may lead to some weaknesses that are visible in the lithium supply chain, described as the midstream paradox in this thesis. Securing raw lithium ore provides little strategic security if the capacity to refine it into battery-grade chemical components is concentrated outside Europe. Furthermore, the EU's plan to process 40% of its needed lithium domestically is limited by difficult economic conditions and high energy and labor costs. That said, the European capacity for refining and processing is less competitive compared to Chinese refining industries that benefit from government subsidies and cheap coal-based energy (Leichthammer, 2025). Furthermore, the current CRMA appears to be unable to bring lithium refining capacity back to Europe because, without stable long-term demand, guaranteed purchase agreements, and price-stabilization mechanisms, investors may not accept the risk to build new refining facilities inside Europe (Defard & Voïta, 2024; Leichthammer, 2025).

In the case of rare earth elements, the structural limitations of the CRMA become even more visible because the issue is not limited to extraction and refining, but also extends to highly specialized downstream industries such as permanent magnets.

[17] An Environmental Impact Assessment (EIA) is a process used to evaluate the likely environmental effects of a proposed project before it is approved. It examines potential impacts on areas such as biodiversity, water resources, ecosystems, and human health and provides opportunities for affected communities and stakeholders to participate in the decision-making process.

Therefore, the CRMA's extraction and processing benchmarks alone are unlikely to create a self-sustaining industrial ecosystem that can compete with other supply giants because activities across all stages of the supply chain remain underdeveloped in Europe (Kalantzakos, 2020; Rietveld et al., 2022). Furthermore, unlike the United States, which has adopted large-scale legislation to subsidize clean energy manufacturing, the European approach still lacks a large-scale financial instrument and instead relies heavily on fragmented national state aid and private investment. This further limits Europe's ability to develop a competitive domestic rare earth ecosystem capable of challenging established state-backed monopolies (Findeisen & Wernert, 2023).

The external geopolitical fragility of the cobalt supply chain is another case that shows the limitations of the internally focused nature of the CRMA. Since the majority of global cobalt are extracted in the Democratic Republic of Congo, European industries are exposed to an instability nexus created by weak governance, systemic security threats, and severe human rights concerns (Vandome & Dideberg, 2025). Similar to lithium and rare earth elements, the CRMA's strategy to manage this fragile supply chain appears insufficient in the short-to-medium term. Europe attempts to manage this vulnerability by promoting diplomatic partnerships and diversifying raw material imports, as other global suppliers are not capable of reaching even close to the DRC's position in the cobalt value chain. Furthermore, Chinese state-backed companies have already created deep commercial and infrastructural networks within the Congolese mining sector to ensure that extracted cobalt are sent directly to China for refining (De Decker, 2023). Therefore, unilateral European market policies and Memorandums of Understanding (MoUs)[18] seem inadequate to reduce the deeply integrated Sino-African cobalt network or stabilize a historically fragile supplier state (Vlaskamp, 2024).

To address the difficult challenges related to domestic mining and dependence on foreign refining and processing, European policies strongly support a circular economy, meaning that materials can be recycled and reused after they reach the end of their life cycle. The objective is to cover 25% of strategic raw material demand through domestic recycling. Indeed, expanding secondary material markets is important for Europe's long-

[18] A Memorandum of Understanding (MoU) is a formal but generally non-binding agreement that establishes a framework for cooperation between parties and outlines shared objectives, areas of collaboration, and mutual commitments.

term resilience, but the circular economy provides only a limited short-term solution to the current materials security dilemma. The main problem is related to time. Large-scale recycling of lithium, cobalt, and rare earth elements depends on the availability of end-of-life waste streams, such as used electric vehicle batteries and renewable energy infrastructure. However, most of these technologies are still in use and are not expected to reach the end of their life cycle until the late 2030s and 2040s (Gregoir & van Acker, 2022). Until this large volume of secondary materials becomes available, the European Union is more likely to continue relying on primary extraction and processed imports. This way, the recycling benchmark is less likely to be achieved in the current decade (Righetti & Rizos, 2023). Moreover, recycling complex technologies such as permanent magnets at a high volume needs significant technological innovation and better coordination of waste-management systems, which are not developed yet in Europe (Defard & Voïta, 2024). As a result, recycling is an important part of Europe's strategy for future autonomy, but it is not a short-term solution to meet the CRMA benchmarks.

Examining the CRMA through specific material supply chains shows that the framework identifies the main vulnerabilities of the green transition, but policy instruments still face important structural limitations. Accelerating administrative procedures cannot significantly reduce the long geological and industrial timelines required for mining projects, and non-binding processing targets seem to be insufficient to overcome Europe's high energy and labor costs. Similarly, diplomatic partnerships and diversification strategies are less likely to quickly reduce deep geopolitical and industrial dependencies. Nevertheless, the CRMA is an important step toward recognizing the strategic importance of critical raw material supply chains and building future resilience. However, the midstream paradox of lithium, the industrial fragmentation of rare earth elements, and the geopolitical fragilities of the cobalt supply chain suggest that European strategic autonomy will probably continue to be limited by concentrated global supply chains for the coming years, based on what is currently expected.

3.5 Comparative Perspective: Europe and Other Major Powers

Today, the management of critical raw materials has moved beyond the issue of market efficiency and global trade, and it has become a matter of industrial policy, geopolitical competition, and national security (Vivoda, 2023). Surprisingly, traditional liberal markets prefer greater state intervention to secure the raw materials needed for the green transition, as free markets alone are not capable of doing so. The European Union's approach to securing raw materials is the introduction of regulations and benchmarks to balance open-market principles with stronger supply-chain resilience (Allan and Nahm, 2024; D'Amico, 2024). On the other hand, other major powers have adopted more direct interventionist approaches. For example, the United States has used subsidies and industrial policies to promote reindustrialization and "friend-shoring."[19] This strategy aims to change the direction of supply chains towards politically reliable partners in order to reduce potential risks (Driscoll et al., 2026). China, meanwhile, has worked for decades to take control of the critical raw materials market through state-backed companies, vertical integration, and industrial coordination (Rhodium Group, 2025; Araújo et al., 2026). Japan has a different story: the state has close cooperation with corporations, focuses on overseas investments, and started developing diversification strategies after the trade disruption that happened in 2010 (Vekasi, 2018). That said, CRMs play a central role in geopolitical competition and national security planning.

The United States has integrated its critical raw materials strategy into a broader industrial policy—particularly the Inflation Reduction Act (IRA) and the Defense Production Act (DPA)—which heavily relies on state financial intervention (Driscoll et al., 2026). In comparison with Europe, which focuses on regulations, standards, and multilateral coordination, the United States uses financial incentives to expand domestic production and encourage "friend-shoring" of manufacturing and processing activities (D'Amico, 2024). The U.S. government gives tax benefits to companies that follow specific sourcing conditions by linking clean energy tax credits to specific sourcing rules (U.S. Congress, 2022). This means that a specific percentage of the battery minerals should come from the United States or from allied countries that have free-trade agreements with the U.S.; otherwise, the company may not qualify for those benefits. This way, the use of materials processed by strategic rival entities will be limited (U.S. Congress, 2022; Cheng et al., 2024). More importantly, the U.S. is building its supply

[19] Friend-shoring" (or ally-shoring) is a trade practice where supply chain networks are deliberately redirected away from geopolitical rivals and concentrated within countries that share common values, political alliances, and security interests.

chain with geopolitical alliances and trusted partners—a more assertive approach than the EU's broader de-risking strategy (Vivoda, 2023; E3G, 2024). The U.S. has many institutions involved in critical minerals policy that can make coordination difficult, and to deal with this, the U.S. uses its large market power and clean vehicle tax credits to pressure companies to follow U.S. sourcing rules and to encourage foreign companies to invest in the United States (Crebo-Rediker, 2025).

China's approach to critical raw materials is based on long-term planning that involves ecosystem building, vertical integration, and industrial coordination (Rhodium Group, 2025). China does not prioritize subsidies or "friend-shoring" alliances; instead, the focus is to integrate all stages of the supply chain (upstream extraction, midstream processing, and downstream manufacturing) into a coordinated system (Allan and Nahm, 2024). This integration has been facilitated by institutional interventions, which include merging regional companies and industrial activities into large state-backed enterprises. This has made the country more capable of influencing global prices, manage export volumes, and shape technical standards (RAND Corporation, 2025). China's strategy is to control the most profitable parts of the supply chain, such as processing, refining, and manufacturing advanced products. To do so, the government increases state financing, invests in research and development (R&D), and makes state-owned companies involved in the domestic and global market (Sun et al., 2026).

Furthermore, China has expanded this strategy abroad by buying shares in foreign mining projects, including cobalt mines in the Democratic Republic of the Congo (DRC) and lithium projects in Australia and Chile. The financial support often comes from Chinese state-owned banks. To protect its dominance in supply chains, China uses measures such as export quotas, licensing systems, and restrictions on technology exports, which makes competitors more dependent and complicates diversification efforts (Driscoll et al., 2026; Zhou et al., 2025). This comprehensive state-backed model considers critical raw materials as strategic assets that increase China's influence in the global market and challenge the market-based model of Western economies (Araújo et al., 2026).

Japan has a state-corporate coordination model (a coordinated partnership between the state and businesses) that focuses on supply-chain diversification and risk management. After the 2010 Senkaku/Diaoyu Islands dispute, which caused a sudden restriction of rare earth exports from China, the Japanese government and private sector started putting more efforts into building supply networks less vulnerable to political disruptions (Vekasi, 2018; Kang et al., 2025). Japan recognized that self-sufficiency was not possible; therefore, the government adopted a coordinated internationalization strategy to diversify its sourcing options to reduce the risk of being reliant on a single power (Kang, Lee, and Oh, 2025). This diversification was a pragmatic response to the vulnerabilities created by economic interdependence (Vekasi, 2018).

Japan's institutions, especially the Ministry of Economy, Trade and Industry (METI) and the Japan Organization for Metals and Energy Security (JOGMEC), supported private companies through subsidies, Overseas Development Assistance (ODA), and diplomatic efforts to pave the ground for establishing joint mining and resource projects in regions such as Southeast Asia, Central Asia, and Australia (Kim, 2025). The government also provided financial support and guarantees for private firms to reduce the financial risks of expensive mining investments abroad. This cooperation between the public and private sector helped Japanese companies to create alternative sources for extracting and processing critical raw materials, which, as a result, reduced Japan's dependency on a limited number of suppliers (Moerenhout, 2026; Vekasi, 2018). Japan's experience shows that an industrial policy based on overseas investment, diplomacy, and technological innovation can better strengthen supply-chain resilience than relying only on massive government subsidies for domestic industries (Moerenhout, 2026).

To remain relevant in this market and overcome challenges related to critical raw materials management, governments use different approaches, which are often based on different models of state intervention and economic thinking. The European Union mostly relies on regulations, sustainability standards, and legislative benchmarks while pursuing open strategic autonomy. This approach helps the EU to strengthen domestic capacities but at the same time keep its commitments to multilateral trade and market-based solutions (D'Amico, 2024). On the other hand, the United States uses a high level of subsidies and friend-shoring policies to reshape supply chains in its own favor and build trade networks (Driscoll et al., 2026). China follows a state-centered model: strong government coordination, vertical integration, industrial policy, and foreign policy to stay dominant in all stages of critical raw material market (Rhodium Group, 2025; Sun et al., 2026). Japan, meanwhile, shows how overseas investment and close cooperation between the government and private sector can reduce supply chain risks (Vekasi, 2018; Kim, 2025). The main challenge for Europe in this context is to ensure that its regulatory and benchmark-based framework remains effective in a market where other major powers intervene more directly to secure their position and gain strategic advantages (Boehm and Scalamandre, 2023). Overall, securing critical raw materials requires a combination of industrial policy, international cooperation, and diplomatic engagement to respond to geopolitical and economic competition.

In conclusion, while the Critical Raw Materials Act represents an important shift from reliance on market forces toward a more strategic approach to raw material security, it cannot fully overcome the structural vulnerabilities embedded in global supply chains. As this chapter has demonstrated, the framework can improve resilience through diversification, domestic capacity-building, and stronger coordination, but significant challenges remain. The concentration of lithium refining, China's dominance across rare earth value chains, and the governance and stability issues affecting cobalt supply cannot be resolved through EU policy alone. Moreover, the development of new extraction, processing, and recycling capacities requires substantial investment and long implementation periods. As a result, the CRMA may reduce Europe’s exposure to external shocks, but it is unlikely to bring significant changes to Europe's material dependencies or fully reach its targets by 2030. This raises broader questions about how Europe’s material dependencies may evolve in the coming decades, which are explored in Chapter 4 through an analysis of future scenarios and geopolitical developments between 2030 and 2050.

Chapter IV

Future Scenarios (2030–2050)

4.1 The 2035–2040 Adaptation Window

The time period between 2035 and 2040 will be a critical adaptation window for Europe and the global energy transition. The European Union is moving to reach its mid-century decarbonization targets (e.g., achieving climate neutrality by 2050 and reducing net greenhouse gas emissions by at least 55% by 2030), and at the same time, the demand for electric vehicles, wind turbines, and grid infrastructure is growing and expected to grow rapidly during this period as a result of the green transition and Europe's strategic need. This increases pressure on the physical and structural capacity of existing supply chains in Europe (World Bank, 2017; IEA, 2021). The shift to renewable energy is not a simple shift and can be decisive because states need to fundamentally reassess their strategic autonomy and move their focus to managing a complex industrial and material dependency in a complicated supply chain (Scholten et al., 2020; Ivančík and Dušek, 2026). Moreover, addressing the challenges related to the management of this dependency requires close attention to public opinion, local community acceptance, and the effectiveness of environmental governance (Lesser et al., 2021).

By 2040, as demand continues to grow, the vulnerabilities which are inherent in such a supply chain (highly concentrated) will become more exposed than before. Today, the most important stage of the CRMs supply chain, midstream, is heavily controlled by China, and this has caused critical raw materials to be viewed through a security lens. Concerns over potential resource weaponization and resource nationalism are likely to push Europe to reshore extraction activities and diversify its supply networks (Farrell and Newman, 2019; Gholz and Hughes, 2021). However, building new extraction and refining infrastructure requires substantial capital investment and a stable commodity market, making it uncertain under conditions of current financial and commodity volatility. Furthermore, since mining projects take a decade or more, if investment does not keep pace with demand growth, supply will not increase fast enough to meet future demand (Greim et al., 2020; IEA, 2021). At the global level, supply security also depends on the institutional capacity of supplier countries, as resource-rich regions with weak governance structures and social instability are less likely to provide a secure supply (Church and Crawford, 2018; IRENA, 2023).

The efforts to strengthen strategic autonomy through domestic extraction in Europe are facing challenges created by the strict environmental regulations of states. Approximately 85% of Europe’s critical mineral deposits are located near or under protected environmental areas, including the Natura 2000 network (Correia and Falck, 2025; Ovaskainen et al., 2026). Therefore, fast-tracking strategic mining projects is in conflict with the need to protect biodiversity, and it can lead to long legal disputes and public criticism regarding the potential degradation of water resources and protected habitats (Eerola, 2022; Murguía et al., 2016). When public opinion perceives that governments are bypassing environmental protections, trust in public authorities may erode gradually; therefore, the economic and political success of mining projects is highly dependent on the ability of institutions to manage conflicts and convince public opinion (Tost et al., 2021; European Union, 2024).

Therefore, the efforts to secure access to raw materials through extraction are limited by public opinion and the requirement of obtaining a Social Licence to Operate (SLO) (Boutilier and Thomson, 2011; Prno and Slocombe, 2012). Rural areas in Europe often oppose extraction projects because of concerns that extraction activities degrade the environment and turn these areas into sacrifice zones, meaning that the locals bear the costs of a wider green transition but others (e.g., private companies) benefit from it (Scott and Smith, 2017; Auvet and Arnauld de Sartre, 2026). This local resistance, often described as "Not In My Backyard" (NIMBY) opposition, is capable of delaying or blocking important strategic projects when procedures are not fair, public engagement is not transparent, or benefit-sharing is not adequately addressed (Badera and Kocoń, 2014; Lesser et al., 2021). When strong social legitimacy at the local and societal levels does not exist, even political support for the energy transition may gradually weaken, and finally it may lead to fragmented policies and stranded assets (O'Faircheallaigh, 2015; Jartti et al., 2020).

These drivers will shape the future of Europe's energy security with two alternatives. The way Europe responds will determine whether it moves toward resilience or toward fragmentation and disruption. For example, the Beigua titanium case in northwestern Italy shows a tension between strategic mineral development and environmental protection of the region (Sabra, 2023). Piampaludo deposit is registered under UNESCO Global Geopark and the Natura 2000 network, while at the same time it is considered one of the largest titanium deposits in Europe (Sabra, 2023; Marescotti et al., 2022). However, the area is known for its rich biodiversity and environmental value, and extraction would produce large amounts of waste and threaten the landscape and collective heritage. That is why the project has faced strong opposition from local communities and municipal authorities, which believe that the area would become a sacrifice zone for a broader benefit. Similarly, the limitations caused by restricted access to water resources along with strong local opposition in lithium mining areas such as Covas do Barroso in northern Portugal show the socio-environmental limits of extraction (Vera et al., 2023; Dunlap and Riquito, 2023).

Meanwhile, rare earth projects in northern Sweden and northern Finland highlight complex regulatory challenges and the rights of Indigenous peoples in this process (Eerola et al., 2024). An example outside Europe that affects Europe is the cobalt case, where instability in cobalt-producing regions highlights the governance and human rights vulnerabilities of concentrated global supply chains (Alves Dias et al., 2018; Bille, 2025).

As a result, in addition to the availability of geological resources or economic support, Europe needs to deal with a complex combination of political decisions, geopolitical dynamics, environmental governance, and social legitimacy to be able to navigate the 2035–2040 adaptation window. Depending on the way the European Union manages these pressures, two different futures may emerge. These scenarios are explored in the following sections: Scenario A: Fragmentation and Disruption, characterized by geopolitical rivalry, resource nationalism, political resistance, environmental limitations, and local opposition, and Scenario B: Resilience and Strategic Adaptation, characterized by supply diversification, international cooperation, long-term investment, high social acceptance, fair environmental governance, and stronger supply-chain resilience.

4.2 Scenario A: Fragmentation and Disruption

This scenario describes a future where fragmentation, instability, and persistent difficulties challenge secure access to critical raw materials needed for decarbonization. In the case that Europe and the international system fail to navigate the 2035–2040 adaptation window, the energy transition and Europe's infrastructure building will slow down gradually as a result of systemic challenges, including geopolitical rivalry, economic fragility, environmental limitations, governance failures, and a lack of social legitimacy, which may disrupt global supply chains (World Bank, 2017; IEA, 2021). These drivers may negatively affect Europe and shift the risk from a theoretical level to a structural reality.

Geopolitical rivalries and resource weaponization, which have been well discussed in the previous chapters, will play an important role if the fragmentation scenario happens. Major powers may treat critical raw materials as zero-sum strategic assets, which can make resource weaponization even more likely (Farrell and Newman, 2019). Specifically, China, which controls important stages of many strategic raw materials supply chains, will have the possibility to use diplomatic leverage during broader geopolitical disputes, as Beijing did in September 2025 as a response to United States tariffs (Farrell and Newman, 2019; Teer, 2025). Furthermore, resource-producing countries may adopt aggressive forms of resource nationalism in response to such an international environment. These countries can partially ban exports, expropriate foreign-owned assets, and move towards building domestic capabilities to process raw materials. This has already happened with Indonesia's restrictions on raw nickel exports and its efforts to expand domestic processing capacity (Kowalski and Legendre, 2023; IRENA, 2023; IEA, 2024). Therefore, in addition to instability in some resource-producing countries, Europe is likely to face leverage in both extraction and refining stages: resource nationalism and resource weaponization.

The friction in this scenario will cause the European and global economies to experience slower growth, which, as a result, may make risk-averse financial markets less willing to invest largely in building domestic capacities and diversifying supply networks (Correia and Falck, 2025). Furthermore, political support for the energy transition may erode gradually. The high costs as a result of fragmented supply chains are likely to create tension between maintaining industrial competitiveness and achieving climate objectives. This economic burden at the end falls on industries and consumers, and it may increase political pressure on governments; therefore, the implementation of transition policies might become more difficult, and commitment to decarbonization may decline. Inconsistent policies across different countries may weaken coordinated action, and countries would prioritize short-term national interests and individual resource-security strategies rather than a coordinated European strategy. The big challenge that will come out of these inconsistencies is that the European Union's collective bargaining power will be decreased (Draghi, 2024; Guerrieri and Padoan, 2024).

Domestically, political efforts to reshore extraction will be likely to face public opposition and create a social legitimacy challenge. There is an obstacle to the attempts of European governments and industries to fast-track mining projects: they may find it difficult to obtain a Social Licence to Operate (SLO) due to a lack of public trust in institutions (Lesser et al., 2021; Boutilier and Thomson, 2011). Considering the local and public opposition, the greater the expansion of mining, the greater the possibility of creating anti-mining alliances. This trend is already visible in opposition to lithium projects such as Covas do Barroso in northern Portugal, where local communities are strongly against the possibility that their agricultural heritage could be sacrificed for the broader European green transition. Local populations consider these projects as a form of green extractivism, where natural resources are extracted in the name of environmental sustainability or the green transition but which often reproduces the same social and environmental harms that already exist. Therefore, any initiatives that are considered dangerous for traditional livelihoods may be rejected by local populations (Dunlap and Riquito, 2023; Auvet and Arnauld de Sartre, 2026).

Furthermore, environmental challenges may keep limiting Europe's ability to expand domestic extraction. If conflicts similar to the Beigua titanium case happens across multiple strategic mining projects, permitting processes could become longer and legal disputes become more frequent. Together, these dynamics can create a fragmented and unstable environment in which Europe struggles to secure access to critical raw materials. This scenario is likely to make European Union become vulnerable to external shocks, supply disruptions, and delays in the energy transition.

4.3 Scenario B: Resilience and Strategic Adaptation

In a plausible future if Europe successfully overcomes the structural and political challenges of the 2035–2040 window, the energy transition will continue its path, but the reason will be different: it will not be because geopolitical and environmental challenges disappear but because they are managed by sustained leadership and effective governance. Scenario B describes the future of Europe where governments and industries work together to reduce vulnerabilities and strengthen resource security. A broad political consensus among the EU and the member states around open strategic autonomy plays an important role in making this resiliance possible. European actors may develop governance mechanisms, institutions, and procedures to better manage conflicts, protect the environment, and maintain social legitimacy (Lesser et al., 2021).

The effective implementation of the Critical Raw Materials Act (CRMA) is central to this pathway. If implemented, it means it is supported by strong political commitment across the European Union. The collective actions will help the EU to avoid the limitations of individual approaches by Member States and at the same time strengthen its single market to stay relevant in international cooperation and promote mutually beneficial partnerships (Hool et al., 2024). This long-term policy alignment will be helpful for having regulatory certainty, which is needed for investor confidence. Therefore, both public and private investments are directed towards refining, processing, and recycling infrastructure through the support of financial de-risking mechanisms provided by institutions such as the European Investment Bank (Correia and Falck, 2025).

Europe's ability to secure imports is increased when decision-makers align foreign economic policy with human security and transparent governance in producer countries. The EU recognizes that long-term supply stability becomes possible by local institutional capacity, and to strengthen it, the EU increases its diplomatic engagement and links trade agreements with capacity-building programs in mining regions (Church and Crawford, 2018). For example, in the cobalt case, multilateral cooperation and the enforcement of international due diligence standards, including the OECD guidelines, will be helpful in overcoming governance challenges and instability that have affected the Democratic Republic of the Congo as one of the largest producers of cobalt (OECD, 2017; Sovacool et al., 2020). In this way, Europe will promote transparent extraction practices and cooperation with supplier states, which are important to reduce the risk of sudden disruptions and to improve the ethical legitimacy of the green transition.

Inside Europe, policy frameworks would support technological innovation and help the adoption of reliable strategies for a circular economy. Resource efficiency and eco-design will be improved by long-term industrial planning as demand increases. The EU already supports research and development to accelerate innovation in both lithium extraction and recycling, and in an optimistic future, if the policy is implemented, it is expected to keep moving forward. In addition, improvements in direct lithium extraction and water management are helpful in reducing the ecological footprint and water constraints resulting from brine evaporation in arid regions (Vera et al., 2023). Meanwhile, the expansion of European battery recycling capacity is likely to address midstream processing bottlenecks and ensure that the lithium needed for energy storage is sourced, refined, and reused through secure networks. This way, the EU will face less price volatility, and supply security will be strengthened.

In this scenario, public authorities are successful in communicating the importance of critical raw materials and present resource security as a shared social objective that does not leave locals and public opinion behind (Auvet and Arnauld de Sartre, 2026). Transparent communication and informed public debate will help Member States to maintain public trust and strengthen social legitimacy and will also help to reduce project delays and local resistance. Obtaining a Social License to Operate (SLO) is likely to become mandatory, leading to procedural fairness, transparent dialogue, and respect for human and Indigenous rights, including those of the Sámi people in Northern Europe (Lesser et al., 2021; Frost, 2023). In addition, mechanisms such as Community Development Agreements (CDAs) will be promoted to strengthen this trust and ensure environmental monitoring for local communities (Correia and Falck, 2025). However, some projects (e.g., the Beigua titanium case) remain environmentally or socially unsuitable because of their sensitive biodiversity and the fact that they are located within UNESCO Geoparks.

Ultimately, Scenario B presents a future in which Europe successfully manages the challenges of securing critical raw materials for decarbonization. If successfully implemented, the European Union responds through long-term planning, supply chain diversification, and equitable environmental governance to manage geopolitical tensions, environmental constraints, and social conflicts, which are among the main factors disrupting the energy transition. Therefore, the fragmentation and instability described in Scenario A are avoided. In this future, international cooperation, technological innovation, responsible governance, and the maintenance of social legitimacy together provide resource security, rather than relying solely on extraction.

Conclusion

The transition of the European energy architecture after decades of reliance on fossil fuels represents a major geopolitical shift. For more than half a century, the focus of European economic and foreign policy was to secure access to oil and gas. The move toward renewable energies, accelerated by climate goals and technological progress, was initially seen as a way to reduce these long-standing dependencies. However, as this thesis has shown, decarbonization does not remove geopolitical vulnerabilities; instead, it changes the nature and location of vulnerabilities. The central research question of this thesis examined how resilient Europe is to the potential weaponization of critical raw material supply chains and how effective its policy and industrial responses are in reducing these risks within a highly concentrated global market. The findings suggest that Europe remains structurally exposed to supply disruptions and geopolitical coercion. At the same time, the findings show that Europe is gradually strengthening its ability to respond through a transition from passive reliance on global markets to a more active form of industrial policy aiming to improve resilience and strategic autonomy.

The analysis presented in this thesis has been guided by two key concepts: the material paradox and the geopolitical risks with securing critical minerals. The material paradox shows a central tension of the green transition. Renewable energy technologies reduce dependency on volatile fossil fuel markets but also creates a heavy reliance on a limited number of geographically and industrially concentrated materials. The findings of this thesis support this argument and suggest that Europe has replaced one form of concentrated dependency with another. The concept of supply chain insecurity provides a useful framework for understanding state behaviour under conditions of uncertainty. This framework is often described as a dilemma because efforts to strengthen resilience can unintentionally intensify geopolitical competition, that is why the framework is helpful in explaining many of the dynamics in the analysis. The findings further suggest that these tensions do not emerge primarily from absolute geological scarcity. Rather, they come from the structural uncertainty in the complex global value chains, where processing capacities and technological chokepoints can be strategically leveraged. As major powers implement defensive industrial policies and secure exclusive supply agreements, the international system is becoming fragmented with similar pace. As a result, Europe needs to adapt to an environment in which economic interdependence is no longer considered only as a source of efficiency and cooperation, but also as a potential source of strategic vulnerability.

To better understand these risks, one of the main contributions of this research is its disaggregation of critical raw materials. Rather than treating these resources as a single and uniform category, the comparative case studies of cobalt, lithium, and rare earth elements show that different materials with certain structures create different forms of dependency. The case of cobalt shows an extreme concentration of primary extraction, characterized in this thesis as the instability nexus. In this case, Europe's exposure is closely linked to the fragility of the supplier state, with the Democratic Republic of Congo accounting for approximately 70 percent of global mine production. This case shows the relevance of the resource curse literature by showing how abundant natural wealth, when combined with weak governance, systemic corruption, and security threats, can create risks that affect global supply chains. For Europe, therefore, the dependency on cobalt is not simply an economic concern but also a important security and ethical challenge. The supply of a critical battery component is highly vulnerable to domestic instability in the Democratic Republic of Congo and to the presence of hazardous artisanal mining practices.

In the processing stage, lithium presents a different form of dependency, conceptualized in this thesis as the midstream paradox. Unlike cobalt, lithium reserves are distributed across relatively stable countries such as Australia, Chile, and Argentina. However, the findings show that geological abundance alone does not guarantee supply security when the capacity to refine extracted ore into battery-grade chemical compounds is highly concentrated. The main strategic bottleneck is located in the midstream processing stage, where China holds a dominant position. This case deepens the understanding of resource dependency by demonstrating that vulnerability is not determined only by where a resource is extracted, but also by the industrial processes it must pass through before being integrated into European manufacturing. Europe's limited domestic lithium refining capacity makes its automotive and energy storage industries vulnerable to potential supply disruptions and highlights the limitations of strategies that focus only on diversifying sources of extraction.

The reliance on rare earth elements represents the most comprehensive and persistent dependency among the three case studies analyzed, defined in this thesis as an industrial and technological chokepoint. In this sector, China's influence extends beyond extraction and intermediate refining and encompasses the entire value chain, including the near-monopolistic production of permanent magnets that are vital for wind turbines and electric vehicles. This full-chain dominance is the result of both geological advantages and decades of coordinated state-led industrial policy that built technological expertise, shaped market conditions, and integrated advanced manufacturing capabilities. The case of rare earth elements demonstrates the risks of weaponized interdependence. The 2010 export restrictions imposed on Japan, together with the 2025 licensing requirements that affected European industries, suggest that dominant actors can leverage industrial chokepoints to pursue geopolitical objectives. Europe's exposure in the rare earth sector is significant because reducing this dependency requires more than opening new domestic mines. It requires rebuilding a complex and highly specialized industrial ecosystem that was gradually abandoned over several decades.

In response to these diverse and interconnected dependencies, the European Union has adjusted its policy framework, moving from reliance on free trade to a strategy of open strategic autonomy. The Critical Raw Materials Act (CRMA) is the cornerstone of this new approach and represents the EU's first major attempt to intervene directly in critical raw material supply chains through targeted industrial policy. The strengths of the CRMA are considerable. First, it recognizes the complex nature of the green transition by having clear targets not only for domestic extraction, but also for processing and recycling. By acknowledging that processing bottlenecks (such as those identified in the lithium case) are as important as extraction monopolies, the framework focuses on the industrial stages where Europe's vulnerabilities are most located. In addition, the CRMA aims to strengthen Europe's adaptive capacity through a range of institutional measures, including joint purchasing mechanisms, mandatory supply-chain stress tests, and more centralized governance structures. Together, these measures can help critical raw material procurement elevate from a fragmented national concern to a strategic European priority.

Despite these strengths, a careful evaluation of the CRMA reveals several structural limitations that may reduce the EU's ability to fully protect itself from external disruption and the overall risks of the market. One of the main weaknesses is the non-binding nature of its 2030 targets. The framework does set ambitious goals for extraction, processing, and recycling capacity, but it does not provide the large-scale centralized financial support needed to ensure their achievement. This limitation becomes evident when the EU is compared with other major powers. The United States has deployed substantial federal subsidies through the Inflation Reduction Act to accelerate the reshoring of strategic supply chains, and China relies on state-owned enterprises and coordinated industrial planning to maintain its dominant position. On the other hand, the European Union depends mainly on a fragmented system of national state aid and private investment. As a result, European processing industries face a significant competitive disadvantage, especially given the high energy and labor costs.

In addition, the CRMA's reliance on domestic extraction to meet its primary targets faces significant socio-political and environmental challenges. Although the "Strategic Projects" designation is intended to accelerate administrative procedures, it cannot easily overcome the realities of environmental issues and public acceptance. As demonstrated by resistance to lithium mining in Portugal, opposition to titanium extraction in Italy's Beigua region, and conflicts with Indigenous Sámi communities in Northern Europe, efforts to expand domestic supply are often in conflict with environmental protection and human rights concerns. Without a strong Social License to Operate, many of these projects are facing the risk of being involved in complicated legal disputes and public opposition that can slow the capacity expansion expected by the CRMA. In addition, the recycling targets, which are vital for achieving long-term circularity, are less likely to provide significant relief from current material pressures. The large volumes of secondary materials needed to support the transition will only become available once the current generation of green technologies reaches the end of its life cycle, which is expected to occur in the late 2030s.

As a result, to assess whether the CRMA is sufficient to address Europe's systemic dependencies, the analysis suggests that it is a necessary but currently insufficient framework. It is highly effective in identifying the structural sources of dependency and in establishing the institutional architecture needed for coordinated risk management. However, it lacks the financial resources, industrial coordination, and immediate mitigation measures required to fully address the deeply-rooted Sino-African cobalt networks, the Chinese dominance of lithium processing, and the rare earth industrial and technological chokepoint in the short to medium term. Europe's capacity to resist coercion has improved, as recent policies seek to reduce concentrated risks through international diversification and strategic partnerships. Even so, the continent is still highly vulnerable to potential supply disruptions and external shocks.

These findings have important implications for European energy security and for the geopolitics of the decarbonization era. As the analysis of the 2035–2040 adaptation window suggests, the European Union is entering a period where bases of its economic and energy models are being tested. The central argument of this thesis is that the transition from fossil fuels to renewable energies does not lead to energy independency. Instead, it transforms the nature of dependency, shifting it from a reliance on the supply of oil and gas to a structural dependence on the critical raw materials needed to build green technologies and infrastructure. This shift means that supply chain security is no longer concerned only with access to fuel. It also depends on access to, and control over, the industrial ecosystems that support low-carbon technologies, from extraction and processing to advanced manufacturing. If the European Union fails to properly fund its industrial ambitions, it will become fragmented internally, or if it cannot manage the socio-environmental conflicts created by domestic mining, it could face a prolonged period of disruption. In such a scenario, critical raw material dependencies could be weaponized that can slow the decarbonization process and weaken political support for the green transition.At the same time, a more resilient outcome remains possible. If the EU strengthens its diplomatic engagement, invests in recycling and circularity, and secures broad social legitimacy for its policies, it will be in a better position to manage the risks of the green transition.

Ultimately, the main challenge facing the European Union is to recognize that the era of obtaining sources through global markets without major constraints or geopolitical considerations has ended. The energy transition needs a long-term strategic engagement with the realities of material dependency, and the acknowledgment that replacing reliance on fossil fuels with reliance on critical raw materials creates a new set of geopolitical constraints. The strategic objective for Europe should not be self-sufficiency or to eliminate all forms of external dependence, as such a goal is neither geologically possible nor economically logical. Instead, this research argues that the result of European open strategic autonomy is better tested based on the effectiveness level of interdependence management. By diversifying supply networks, developing technological leadership in processing and circularity, and aligning industrial policy with a coherent foreign policy strategy, Europe can reduce its exposure to coercion and external shocks. The future of European energy security will therefore depend not on achieving complete independence, but on building resilient, diversified, and adaptable forms of interdependence capable of supporting decarbonization while limiting strategic vulnerability.

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