

Managing dependence on scarce natural resources: how institutional logic and autonomy shape supply chain strategies

Francesco Ghezzi, Francesco Rizzi, Eleonora Annunziata and Marco Frey
Sant'Anna School of Advanced Studies, Institute of Management, Pisa, Italy

Abstract

Purpose – Supply chain (SC) strategies are heavily influenced by companies' dependence on natural resources, particularly when they are in a condition of scarcity. Although natural resource scarcity (NRS) represents a significant strategic dimension in SC management, theoretical development remains scarce in the SC literature. This paper aims to offer insights into the interplay among SC strategies, strategic drivers and strategic levers from a Natural Resource Dependence Theory (NRDT) perspective.

Design/methodology/approach – This paper is based on seven case studies conducted within the Rare Earth Magnets industry in Europe, which plays a crucial role in the context of NRS. The authors use a constructivist approach to gain a deep understanding of each case study as well as the broader context in which these SCs operate.

Findings – This paper reveals six SC configurations linked to two strategic drivers, namely, institutional logic and autonomy in the SC. For each configuration, strategies (buffering vs bridging) and strategic levers are analysed and discussed.

Originality/value – This paper reveals the coexistence of diversified strategies to manage dependence on scarce natural resources. It argues that NRS favours the interplay between bridging and buffering strategies, as companies are more prone to collaborate along the SC in conditions of high ecological uncertainty. The paper contributes to NRDT at the SC level by showing how institutional logic and autonomy drive SC strategic responses to NRS. Moreover, it establishes new findings regarding how the strategic levers could be used in managing resource dependencies in SC.

Keywords Supply chain, Natural resource dependence theory, Critical raw materials, Natural resource scarcity, Sustainability, Rare earth elements

Paper type Research paper

1. Introduction

Natural resource scarcity (NRS) is a growing global issue that has several impacts at all business levels. NRS can arise locally or globally, both for non-renewable resources like coal, oil and minerals and for renewable ones like water, wood and agricultural products. The clean energy transition is seriously conditioned by NRS as it shifts resource needs from coal, gas and oil, which power traditional internal combustion engines, to lithium, nickel, cobalt and other critical raw materials such as rare earth elements (REEs), which are crucial to the emerging technologies but also driving factors of supply chain (SC) disruptions in the next future because of a mismatch between their rising demand and their availability (IEA, 2021).

In this regard, the Natural Resource Dependence Theory (NRDT), which extends the Resource Dependence Theory (RDT) “because of its focus on external dependence on scarce resources and the uncertainty that it creates” (Tashman, 2021, p. 1280), introduces NRS as a critical factor shaping organizations' strategy, particularly in situations where firms are dependent on scarce natural resources (Tashman, 2021), whose access is threatened by ecological boundaries or

controlled by external actors (Rockström *et al.*, 2009; Wang *et al.*, 2008). However, little attention has been paid to how companies introduce NRS into SC strategy formulation. To advance the research on NRS, an SC management perspective is necessary “to explain the mechanisms of influence of indirect natural resource dependence through other organizations, as well as strategies for managing it” (Tashman, 2021, p. 1305). In fact, despite its crucial role in businesses' survival (Bergmann *et al.*, 2016; Tashman and Rivera, 2016; Dias *et al.*, 2022) and its strategic relevance for firms (Kalaitzi *et al.*, 2018), NRS and the related mitigation strategies have been relatively

© Francesco Ghezzi, Francesco Rizzi, Eleonora Annunziata and Marco Frey. Published by Emerald Publishing Limited. This article is published under the Creative Commons Attribution (CC BY 4.0) licence. Anyone may reproduce, distribute, translate and create derivative works of this article (for both commercial and non-commercial purposes), subject to full attribution to the original publication and authors. The full terms of this licence may be seen at <http://creativecommons.org/licenses/by/4.0/legalcode>

The authors are grateful to the European Institute of Innovation & Technology Raw Materials (EITRM) for the technical support and for the access to its network, which is deeply connected with the whole critical raw materials industry in Europe. Without this support, it would have been impossible to carry out this work.

Received 30 May 2024
Revised 25 November 2024
25 February 2025
15 April 2025
23 April 2025
Accepted 24 April 2025

The current issue and full text archive of this journal is available on Emerald Insight at: <https://www.emerald.com/insight/1359-8546.htm>



Supply Chain Management: An International Journal
30/7 (2025) 38–59
Emerald Publishing Limited [ISSN 1359-8546]
[DOI 10.1108/SCM-05-2024-0358]

underexplored in SC literature compared to other types of SC risks (Bell *et al.*, 2012; Bell *et al.*, 2013; Kalaitzi *et al.*, 2018; Kalaitzi *et al.*, 2019). Particularly, to the best of the authors' knowledge, no empirical studies have investigated the connection between the natural resource dependence in the SC and the strategies adopted to manage it, systematically linking this connection with strategic drivers and levers that companies use to mitigate the dependence. To fill this gap and increase our understanding of how NRS enters strategic SCM decision-making, we analyse strategies (what), strategic drivers (why) and strategic levers (how) adopted by firms to manage dependence on scarce natural resources. Thus, our research examines the following research questions:

- RQ1.* Which SC strategies do companies adopt to manage dependence on scarce natural resources?
- RQ2.* Which strategic drivers determine SC strategies to manage dependence on scarce natural resources?
- RQ3.* Which strategic levers are leveraged to manage dependence on scarce natural resources?

We adopt the REEs industry in Europe, which is highly dependent on China (around 95%) for primary sources of raw materials (IEA, 2021), as our research setting because of the intense power relations at an industrial and political level and the organizations' exposure to uncertainty related to NRS. We conducted extensive qualitative research, using a multiple-case study methodology, where all major industrial actors were contacted to be part of the study. Building on NRDT and RDT, we identify the relevant SC strategies (*buffering vs bridging*), the strategic drivers that direct the adoption of the different strategies (*institutional logic* and *autonomy*) and the actionable strategic levers, namely, Importance of the Resource (IR), Supplier's Substitutability (SS) and the Discretion over the Resource (DR) (Pfeffer and Salancik, 2003; Kalaitzi *et al.*, 2018).

The paper offers a theoretical contribution that lies at the interface between NRS and SC management (Bell *et al.*, 2012; Kalaitzi *et al.*, 2018; Kalaitzi *et al.*, 2019). In fact, to the extent of our knowledge, it is the first to empirically study SC strategies, strategic drivers and levers using NRDT as the theoretical framework, drawing detailed findings about the interplay between SC strategies and strategic drivers and revealing the role of IR, SS and DR in leveraging over the strategic solutions identified in the various cases.

2. Theoretical background

2.1. A natural resource dependence view of the supply chain

Tashman (2021) proposed the NRDT theoretical framework to understand how organizations manage their dependence on natural resources, incorporating socio-ecological systems, ecosystem scale and institutional logic as key elements. Unlike traditional RDT, which focuses on inter-organizational networks, NRDT focuses on socio-ecological systems, which are dynamic and complex systems composed of interacting physical, biological and social elements (Chapin *et al.*, 2009). The concept of socio-ecological systems considers that ecosystems are not just sources of resources but adaptive

systems influenced by human activity. Through this concept, NRDT captures socio-ecological processes that create resource scarcity that was not addressed in RDT (McGinnis and Ostrom, 2014). Different from transactional inter-organizational networks, socio-ecological systems are inclusive systems where natural and human processes affect organizational dependencies (Tashman, 2021). A socio-ecological perspective is appropriate for connecting SC strategies to uncertainties arising both from the natural scarcity of raw materials and from the socio-economic and geopolitical processes that influence the availability of the resource itself, as for companies operating in the REEs' permanent magnets industry (Table 1). By focusing on socio-ecological systems, NRDT has been used to study various natural scarce resources and their implications for business, such as snow precipitation and ski resorts (Tashman and Rivera, 2016), small agricultural farms (Dias *et al.*, 2022), energy (de Abreu *et al.*, 2017), oil and gas (Bowen *et al.*, 2018) and wine (Galbreath *et al.*, 2020).

NRDT posits that the scale of the ecosystem service influences how organizations perceive and manage uncertainty due to natural resource dependence. Local ecosystems, where resources can be controlled, often encourage private, individualized management strategies. In contrast, larger, geographically dispersed ecosystems lead to systemic uncertainty, requiring collective approaches involving multiple stakeholders (Ostrom, 1999). Thus, the ecosystem scale determines whether organizations view ecosystem uncertainty as manageable independently or necessitating cooperative governance structures (Tashman, 2021). When firms face a non-local scarcity of a provisioning service, namely, a tangible natural resource that organizations source and consume, like in the case of REEs' permanent magnets firms, the systemic uncertainties induce organizations to adopt a collaborative SC approach, especially with the direct suppliers of the scarce resource they are dependent upon (Table 1).

NRDT introduces two contrasting institutional logics that shape organizational approaches to resource management: *economizing* and *ecologizing*. Economizing logic frames natural resources as private assets for efficiency and profit maximization, whereas ecologizing logic emphasizes sustainability and public welfare, seeing natural resources as finite public goods (Hoffman and Jennings, 2021). Organizations aligning with economizing logic often use eco-development strategies to optimize resource output, sometimes degrading non-critical ecosystem services. Meanwhile, those following ecologizing logic use eco-mitigation strategies, focusing on conservation and ecosystem health (York *et al.*, 2016; Berchicci and King, 2007). Reasonably, the institutional logic's spectrum is influenced by the level of active agency the firm has in relation to institutional processes (Oliver, 1991). In fact, as the active agency of the organization passes from passivity to increasing active resistance, the organization's institutional logic transitions from an ecosystemic logic to a more economizing one (Table 1).

2.2 Supply chain strategies to cope with dependence on scarce natural resources

According to RDT, the relationship between the firm and its external environment revolves around the resources the firm requires and the external stakeholders that have control over

Table 1 NRDT dimensions and their use in the paper

NRDT dimension	Description (Tashman, 2021)	Use in the paper
Socio-ecological system	Complex adaptive systems that directly incorporate ecological components. They consist of resource systems, resource units, institutions, resource users and internal and external feedbacks from other ecosystems	REEs ecosystem, incorporating the geological distribution and physical availability of the raw material, the countries involved and its geopolitical relationships, the firms in the global supply chain from the extraction phase to the usage, the ecosystem of other raw materials as radioactive ones (thorium and uranium) that are found and extracted along REEs
Scale of the ecosystem service	Provisioning, supporting, regulating and cultural ecosystem services operating at different geographic scales, which can be distinguished into local and non-local scales from a management perspective	Non-local scarcity of a provisioning service, which is REEs as raw materials. The dependence on this scarce natural resource is systemic and shared among organizations belonging to the REEs supply chain
Institutional logic	Institutional logics reflects both the formal institutions (rules and formal organizational structures) and informal institutions (values, norms and beliefs) that are inherent in the socio-ecological systems. The <i>economizing logic</i> values individual competition in free markets considering the economic impact of nature. The <i>ecologizing</i> one emphasizes the transformation of environmental governance institutions to promote sustainable use of natural resources and distribute natural resources fairly	Organizations in the REEs ecosystem present a mix of institutional logics, ranging from economizing to ecosystemic one. The degree of active agency in relation to institutional processes varies in accordance with the institutional logic assumed by the firm

Source(s): Authors' own work

them, as they have the power to withhold resources from the firm if their concerns are not taken into consideration (Wry *et al.*, 2013; Oliver, 1991; Pfeffer and Salancik, 2003). The strategical responses to such resource dependencies can be categorized under two general macro-strategies: buffering and bridging (Pfeffer and Salancik, 2003). In this paper, we adopt the conceptualization of strategic responses of Bode *et al.* (2011), whose definitions have been widely used in the SC management literature (e.g. Mishra *et al.*, 2016; Manhart *et al.*, 2020). On the one hand, *buffering* strategies imply adopting measures to manage uncertainty by establishing safeguards that shield the enterprise from the risks associated with procurement. Buffering strategies operate regardless of the existing supply relationships, aiming to reduce supplier dependence and mitigate the likely negative consequences of disruptions (Mezner and Nigh, 1995; Bode *et al.*, 2011). To avoid reliance on single sources, the enterprise implements measures to mitigate shocks, such as increased inventory, flexible production processes, multiple suppliers and SC reconfiguration (Kalaitzi *et al.*, 2018). On the contrary, *bridging* strategies encompass actions to manage uncertainty by expanding and strengthening existing supply relationships or transforming them into procurement partnerships. Bridging strategies operate within the supply relationships by seeking to balance the scarcity of resources by offering suppliers long-term forecasts and contracts and treating them as partners (Mezner and Nigh, 1995; Bode *et al.*, 2011; Kalaitzi *et al.*, 2019). Enterprises using bridging strategies can improve supplier relationships through formal or informal actions. This ranges from building trust with partner firms (e.g. involving them in the definition of product strategies, periodic meetings on the progress of the business), investing in collaborative agreements and enhancing information exchange (Kalaitzi *et al.*, 2018).

Moreover, RDT literature shows that companies should leverage three conditions in establishing their strategy to manage dependence on scarce resources (Kalaitzi *et al.*, 2018; Kalaitzi *et al.*, 2019). These strategic levers are recognized to determine the level of dependency of an organization upon its network of relationships (Pfeffer and Salancik, 2003; Caniëls and Gelderman, 2007): IR, which is the magnitude the resource affects outcomes of the firm; SS, determined by the availability of suppliers and the costs in switching from one to another; and DR, which is the control that the firm has over the resource from a socio-political point of view. The literature provides only limited insights regarding the interplay between buffering, bridging and the three strategic levers. While some studies converge to indicating that IR is positively related to buffering and negatively to bridging (Mezner and Nigh, 1995; Van den Bosch and Van Riel, 1998; Kalaitzi *et al.*, 2018), only the work of Kalaitzi *et al.* (2018) has examined SS and DR. Their findings indicate that high levels of both SS and DR result in fewer buffering and bridging initiatives by companies. However, the limited empirical evidence and insights into the connections between elements of NRDT and SC strategies reveal a significant gap in the literature that requires further investigation.

2.3 Factors driving organizational strategic responses to resource dependence

The seminal work from Mezner and Nigh (1995) demonstrated that bridging and buffering strategies to manage resource dependencies are influenced by the size of the organization and the importance of its resources. As a matter of fact, these two factors determine the power of the organization, which in RDT literature refers to the possibility of resisting external social pressure since it makes it more difficult for

society to revoke its legitimization by widening the breadth of the firm’s operations and the connections with other actors. Particularly, organizational power in external relationships is positively related to the use of buffering strategies from the organization (Meznan and Nigh, 1995; Van den Bosch and Van Riel, 1998; Manhart et al., 2020). This is also in line with Bode et al. (2011), who postulate that dependence on SC partners favours the adoption of buffering and bridging strategies by firms, but as dependence gets stronger, bridging is preferred over buffering as relationship power is unbalanced towards the partner organization. Extending the RDT’s view to the entrepreneurial ecosystem perspective, Roundy and Bayer (2019) argued that nascent entrepreneurial ecosystems depend more on the external environment for critical resources. Adopting Meznan and Nigh’s (1995) lens in this context, they posit that the ecosystem’s size is an antecedent of the ecosystem’s power, thus leading to buffering strategies, whereas the ecosystem’s collaborative values lead to the use of bridging strategies. Coherently, we argue that in an SC perspective, power in external relationships can be proxied by the relative autonomy of the focal organization from its external stakeholders, which results from a combination of factors, including the size of the organization, the level of integration in the SC and its ability to overcome geopolitical barriers in managing the scarce natural resource.

Linking the research objectives and rationale outlined in the introduction with the insights from the literature review, we propose a research framework that integrates strategies, strategic levers and drivers from NRDT and SC management literature to explore how companies address NRS through specific configurations (Figure 1).

3. Research method

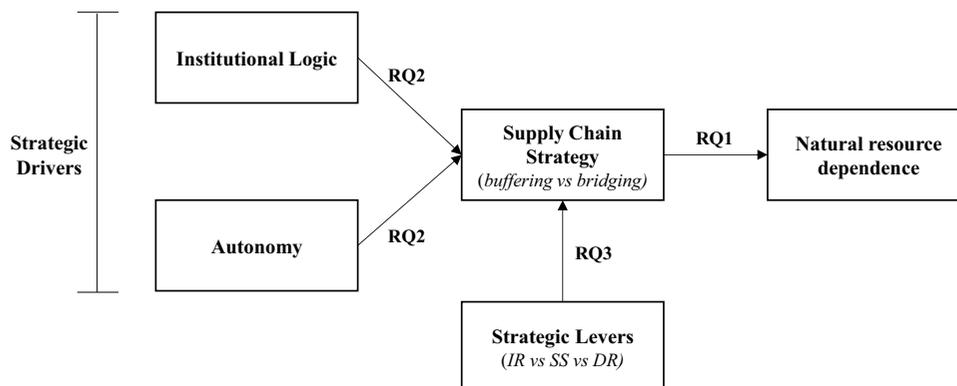
The paper investigates real-world strategic decision-making under NRS from a phenomenon-driven approach (Lumineau et al., 2025). To this end, it uses a multiple-case study method, ideal for refining less-theorized areas like NRS and SC management, by integrating existing theoretical constructs and empirical data, allowing for theory elaboration (Ketokivi and Choi, 2014). A constructivist approach (Ridder, 2017) was used to remain open to unexpected findings while building on

the study’s theoretical foundation. Through open-ended questions and replication logic, the research explores contingent factors related to NRS and SC mechanisms. Although findings may not be universally applicable, the comparative analysis enhances external validity and offers insights extendable to similar industries (Yin, 2014).

3.1 Research setting

To set our investigation, we found the critical raw materials business landscape in Europe appropriate for responding to the research questions because of its exemplary characteristics. Demand for critical raw materials is forecasted to rise by at least four times by 2040 to feed the technologies for the clean energy transition (IEA, 2021). Moreover, from the supply point of view, these materials are deemed critical because of their concentration in one or a few exporting countries in at least one of the SC steps (e.g. extraction, separation and refining). As a matter of fact, from a few years on, increasing pressures from institutional stakeholders have led various European initiatives to spread in an attempt to diminish dependence on third countries and secure a stable flow of critical raw materials in Europe. Initiatives such as the establishment of the European Battery Alliance in 2017 and of the European Raw Materials Alliance in 2020 are among the most relevant ones, as they strive to create a level-playing field in Europe to establish, respectively, batteries and raw materials SCs. In March 2023, the European Commission recognized the strategic role of critical raw materials at a policy level by proposing the Critical Raw Materials Act. The act has set ambitious targets that are challenging to achieve. These are focused on improving supply security to reduce uncertainty and dependencies on third countries by creating in-house primary extraction, diversifying supplying sources and improving recycling and reuse (EC, 2023a). Among critical raw materials industries, we chose the REEs because these materials are heavily involved in the energy transition, especially in the form of Neodimium-Iron-Boron magnets, which are used in wind turbines and rotors of electric vehicles. Notably, demand for REEs magnets in the following years is expected to grow with the adoption of electric vehicles and wind turbines (CEPS, 2022). Furthermore, the European

Figure 1 Research framework



Source(s): Authors’ own work

Union classified REEs as the most critical raw materials because of the huge risks of supply shortage (EC, 2023b).

REEs magnets SC in Europe are scarcely developed (Figure 2). The direct flow of the magnet chain begins with the phase of Exploration and Mining, which is currently still not performed in Europe. Some companies in northern European countries have started exploration activities, but no extraction of REEs ores is currently ongoing (Rare Earth Norway in the Fen complex in Norway; LKAB in the Kiruna district in Sweden; and FMG in the Sokli deposit in Finland).

European companies that perform separation import REEs carbonates from outside the continent (CEPS, 2022). Separation is the SC step in which, by chemical processing, rare earth oxides are isolated from all the other materials in the ores. Oxides go through refining and processing into rare earth metals, which are the input for the manufacturing phase. Magnet manufacturing is a high-value-added phase in which magnets are shaped into specific applications to fulfil end customers' needs. The reverse chain can begin at different points of the direct one since scraps and swarf are generated during refining, manufacturing and final use. Moreover, waste from electrical and electronic equipment (WEEE) represents a source for the recycling chain, as this waste material can be collected, dismantled to extract the magnetic components and then recycled. Depending on the quality of the input magnet, the recycling phase can be performed through two different technologies: direct recycling entails a new shaping of already magnetized powders (making the quality of the output strongly dependent on the quality of the input), whereas indirect recycling is a new separation process with secondary materials instead of virgin ones (CEPS, 2022).

3.2 Sampling

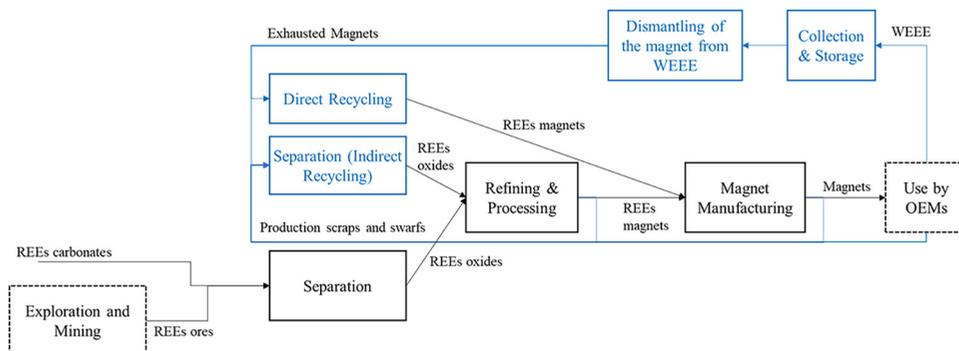
The study focuses on the European REEs magnets SC, a meaningful real-world setting complying with phenomenon-driven research quality criteria related to pertinence, reach, insightfulness, magnification and expediency (Lumineau et al., 2025). Given the lack of significant study constraints regarding participation in the research, we used a purposive sampling strategy (Etikan et al., 2016). The research units were firms that met the following criteria: belonging to the target industry,

centrality of REEs in the firm's business model, representation of the entire SC within the sample [1], inclusion of key European countries with REE SCs and a commitment to participate in the research. Homogeneity was searched in terms of dependence on scarce natural resources within a meaningful real-world research setting. Within this homogeneous setting, we welcomed heterogeneity in other dimensions, such as firms' size, maturity, SC positioning and location (in the various European countries), as these dimensions are associated with different configurations, SC strategies and actionable strategic levers. The authors collaborated with the European Institute of Innovation & Technology Raw Materials. This European consortium supports securing the supply of critical raw materials to the European industry by driving innovation and research along the raw materials value chain. Access to the consortium's network provided the initial contact point for selecting firms to include in our study sample. Then, participation in raw materials events and conferences, such as the Raw Materials Summit 2023, the Raw Materials Week 2023 in Brussels and the Magnetic Materials and Applications 2023 in Hanau, provided occasions of networking and direct contact with the firms operating in the critical raw materials sector. The first author's attendance at such events and engagement with the critical raw materials sector's professionals was fundamental to deeply engaging in the industry's logic and collecting preliminary information and firms' willingness to participate in the data collection phase. The companies were chosen based on their potential to carry valuable and new information to the cases and their willingness to participate in the data collection (Table 2). Considering that a few companies did not agree to participate in the research and that the dimension of the European REEs magnet industry is close to the study sample, we can state that we achieved the highest possible coverage of European organizations working in the chosen industry.

3.3 Data collection

The first and foremost important data collection method was interviews with representatives of the sample firms, held between July and November 2023. Interviewees were primarily CEOs or directors of their firms, but for more structured firms,

Figure 2 REEs magnets value chain



Note(s): The boxes and arrows in black represent the direct chain, and the ones in blue represent the reverse chain. Dotted boxes are not part of the scope of the paper REEs: rare earth elements, WEEE: waste from electrical and electronic equipment, OEMs: original equipment manufacturers

Source(s): Authors' own work

Table 2 Details of case study firms

Case	Location	Organization type	Age (y)	Size*	SC positioning	Case information
A	Italy	Consortium	2	–	Indirect recycling	Case A is in the project phase and is led by two Italian companies. The project is currently proceeding with two streams: one related to the construction of a pilot plant for the recycling of REE magnets, and the other related to the assessment of suppliers of scrap metals, inputs of the plant. The plant is going to implement the hydrometallurgical process of magnet separation (indirect recycling). The positioning in the supply chain as an indirect recycler is critical: the consortium is trying to partner with big manufacturing companies of electronic products to reduce the complexity in terms of the number of different end-of-life magnets treated
B	Spain	Start-up	3	<10	Direct recycling	Case B performs direct recycling by recovering the magnet by transforming the shape or producing powders. It produces powders that can be directly input into magnet manufacturers' machines; thus, their customers are magnet manufacturers. The firm needs as input the magnets already separated and its suppliers are magnet and electric motors manufacturers, recycling companies that manage industrial waste. However, there is no continuous flow of scrap magnets. Case B does not have long-term contracts with suppliers, but only informal agreements based on the temporary availability of some scrap magnets
C	France	Start-up	7	10-50	Direct recycling, magnet manufacturing	Case C is a direct recycler of permanent magnets. It uses a hydrogen decrepitation process to treat scrap magnets and produce powders, and it is positioned in its chain as magnet manufacturer, using its recycled material as input for the production. At the moment, the firm has a plant with 50 t/y magnets capacity. Case C sources materials from all applications where magnets can be found. The scraps are sourced from two different streams: recycling companies (end-of-life magnets), customers (production scraps). Also in this case, the major criticality is the shortage of scraps due to the absence of a market for scraps and to the exporting of scrap material outside Europe to be re-processed
D	Germany	Start-up	4	<10	Direct recycling, magnet manufacturing	Case D is a direct recycling start-up born as a university spinoff. Case D also performs manufacturing of magnets selling directly to original equipment manufacturers (OEMs). The firm has a single supplier of magnet scraps, having signed a memorandum of understanding with a big German primary recycler. The firm also serves as consultant for its own supplier regarding the identification and extraction of magnets inside of scrap products. Case D developed and is developing its recycling capabilities by participating in European R&D projects
E	Estonia	Multinational company	7	~2000	Separation, exploration, magnet manufacturing	Case E is the biggest and most integrated player in the REEs industry in Europe, even if headquartered in Canada with production sites and offices in North America, Europe, China and South-East Asia. In Europe, the firm operates a separation plant that covers the whole separation phase from carbonates to oxides. Besides, it is investing massively to implement a vertical integration strategy both upstream (exploration and mining) and downstream (magnet manufacturing). Its customers are mainly big automotive players

(continued)

Table 2

Case	Location	Organization type	Age (y)	Size*	SC positioning	Case information
F	Germany	National company	101	~1000	Magnet manufacturing	Case F is a long-lived European magnet manufacturer. Its main production plant in Germany has a capacity of 1,000 tonnes per year of magnets. It covers the whole magnet-making phase, from crushing and powder making, to sintering, machining and magnetizing. Magnet production is all customer-specific and covers different applications, serving customers from aerospace, defence, sensors, medical devices and automotive and renewable energies industries. Its suppliers mainly come from China, where it sources from various suppliers in different regions of China to minimize its chances of supply shortages. Suppliers are also coming from Australia, USA and Europe
G	France	National company	5	10–50	Separation, indirect recycling	Case G is a French company focused on creating an industrial project on the recycling of REEs magnets through separation (long-loop recycling). The plant inputs both end-of-life magnets (2k tonnes/y) from which it produces light REEs (neodymium and praseodymium), and mining concentrates (5k tonnes/y) from which it produces heavy REEs (terbium and dysprosium). It holds key relationships with institutional and industrial stakeholders in France, including the national government and the other French players in the REEs industry, whose business models are mainly based on short-loop recycling technologies and therefore complementary to case G's one

Note(s): *n° employees 2023

Source(s): Authors' own work

managing-level professionals were also considered adequately knowledgeable to carry out the interviews. Interviews were based on semi-structured protocol, lasted approximately 1 h and covered multiple topics, from the characteristics of the firm and the technological process used to the stages of the SC covered, from the supplying strategies and issues to the relationships with customers, from the reasons and strategies adopted in managing REEs scarcity to the institutional logic and ties of the firm [2]. As the cases range from start-ups to mature firms, the semi-structured questions allowed the researchers to be flexible and let the interviewees report the most relevant information. Given the qualitative nature of most of the collected data, other sources of information were considered to triangulate data and increase construct validity (Yin, 2014). These sources are secondary data such as annual reports, sustainability reports, news and press releases available from the websites of the sample firms; news and press releases available from other sources; site visits for some of the cases; direct observation of the first author during formal and informal occasions of engagement with firms' representatives; and a validation questionnaire sent to the sample firms during September–October 2024, aimed at a written assessment of the dimensions identified in the previous steps of analysis. In total, we collected approximately 7 h of recorded interviews, 5 h of non-recorded interviews (due to carrying out the interviews during events or conferences without the possibility of recording) for a total of 15 interviews carried out, 4 h of site visits, 45 press releases, 11 reports (sustainability, investors and

products reports), 7 completed questionnaires (one from each case), plus multiple informal verbal and written exchanges with representatives of all case studies (Table 3).

3.4 Data analysis

The data analysis procedure follows the extended case method (López-Gamero *et al.*, 2011). After an initial exploration of the relevant concepts and theories found in the literature, providing the basis for a subsequent comprehensive case description, we run the first exchange with the sample cases by holding, transcribing and coding all the interviews using Gioia's approach (Gioia *et al.*, 2013). The coding method is an abductively derived coder 1-led coding, where the other members of the research team act in the reconciliation of codes (Cole, 2024). As a first step, the first author identified terms and narratives used by the interviewees to describe the SC practices, strategies and strategic levers and also identified all the statements related to the firm's institutional logic, as well as its integration in the SC and degree of autonomy. Thus, he devised the 1° order concepts that adhere to the informants' words. Commonalities and differences among the 1° order concepts were then identified to code them into more general categories called 2° order themes. During this phase, the second and third authors independently processed, debated and reviewed the initial codes. They offered their interpretations and suggested ways to improve and organize the codes into 2° themes and aggregate dimensions. The proposals from the first three authors were then collectively discussed in

Table 3 Data sources

Case	Primary data	Secondary data
A	Three interviews (Strategic Innovation Specialist and Manager, Operations Director), one questionnaire	Two corporate websites and one project website, three press releases
B	Two interviews with the Founder and CEO, multiple email and informal exchanges, one questionnaire	One corporate website, four press releases
C	Two interviews (CEO, CTO), multiple informal exchanges, one questionnaire	One corporate website, seven press releases
D	One interview with the CEO, multiple email and informal exchanges, one questionnaire	Two corporate websites, eight press releases
E	Two interviews with the Director of Corporate Development, multiple informal exchanges, one questionnaire	One corporate website, two publicly available reports, six press releases
F	Three interviews (Director of R&D, Vice President, Product manager), site visit at a production plant, multiple informal exchanges, one questionnaire	One corporate website, four publicly available reports, nine press releases
G	Two interviews (CEO, chief of staff), multiple informal exchanges, one questionnaire	One corporate website, one internal report, eight press releases

Source(s): Authors' own work

joint meetings, incorporating inputs from the fourth author, who contributed with a more detached and objective perspective. To finalize the coding structure, we relied on consensus-building through collective agreement [3] (Cole, 2024). As per the theory elaboration aim of this paper (Ketokivi and Choi, 2014), the 2° order themes are informed by the underlying theories (NRDT and RDT) and adjusted to fit with the 1° order codes. From such a process, themes such as institutional logic and autonomy stand out as key drivers of the strategies adopted by the cases. Themes were finally combined into the aggregate dimensions: *SC strategies*, *Strategic levers* and *Strategic drivers*. The whole data structure for strategies, strategic levers and strategic drivers is presented in Figure 3.

Afterwards, a second exchange phase with the cases was run to obtain feedback on each case's dimensions of analysis through a validation questionnaire. This phase happened several months after the interviews when the researchers had already developed the data structure, which directly informs the design of the validation questionnaire. The analysis of the questionnaires' responses was aimed at spotting discrepancies with the findings of the interviews. We found consistent evidence in terms of SC strategies adopted by each case. Nearly all cases highlighted the critical importance of institutional and regulatory support in the REEs industry and magnetic technological competence for market survival, which are 1° order themes of *DR*, thus representing the main discrepancy between the first and second exchanges.

4. Results

This section summarizes the findings regarding the combined emergence of SC strategies, strategic levers and drivers. Table 4 presents their co-occurrence for each case and proposes labels for six different configurations of strategies, strategic drivers and strategic levers identified among the cases. Appendix 2 Table A2 details the paper's main findings regarding the extracted codes, representative quotations from the cases and the evaluation of the literature's dimensions for each case to provide supportive evidence for the analysis carried out in this section.

4.1 Supply chain strategies

Case study firms adopt SC strategies as buffering or bridging strategies (Figure 3).

4.1.1 Bridging strategies

Among bridging strategies, firms are implementing partnerships both downstream and upstream, respectively, with original equipment manufacturers (OEMs) and suppliers. They are intensifying the information exchange with their partners and/or pursuing a vertical integration strategy. Cases A and G, for example, are separators of REEs trying to implement indirect recycling processes. In this configuration, companies input dismantled magnets in the recycling process, thus relying on a supply of secondary material. Continuity of the input flow of separated magnets is vital for these companies because the separation plant implements a chemical process of separation that requires a stable flow of input to work properly. Anyway, continuity of the secondary input is critical because:

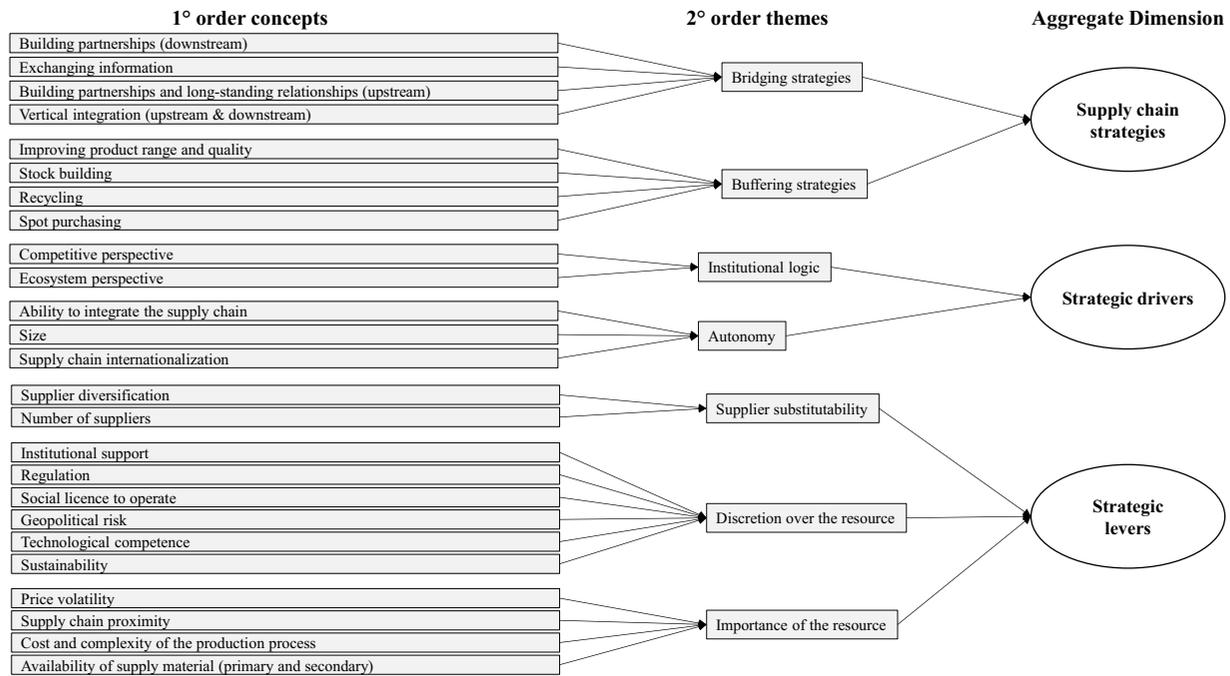
- there are few magnet makers in Europe, and the availability of magnet scraps on the market is low;
- there is no standard and little information regarding the presence of magnetic content in electronic waste, the relative magnets' concentration, the feasibility of finding and extracting the magnetic part from electronic equipment; and
- the exchange of information around waste from electronic equipment is limited.

In this context, companies tend to partner with big manufacturers of electronic products to reduce the complexity of the number of different end-of-life magnets treated. Such partnerships could increase interaction among SC members, provide information on the potential value of electronic waste and increase identification capacity.

The consortium is working with technology manufacturers to investigate the presence of REEs in their products. [...] We are certain that inside (the products) there is neodymium when we have the certainty from the manufacturer. [Case A]

For the same reasons, companies also look for industrial partnerships with recycling companies: they provide the

Figure 3 Data structure



Source(s): Authors' own work

Table 4 Assessment of strategies, strategic levers and strategic drivers in the case studies

Case	Buffering	Bridging	SS	DR	IR	Institutional logic	Autonomy	Configuration
A	0	X	0	0	0	Ecosystemic	Low	Cog in the network
B	X	0	X	0	0	Economizing	Low	Niche company
C	X	0	X	0	X	Economizing	Medium	Focused company
D	0	X	0	X	0	Ecosystemic	Medium	Regional network
E	X	X	X	0	X	Economizing	High	Autonomous company
F	X	X	X	X	0	Ecosystemic	High	Regional ecosystem
G	0	X	0	X	0	Ecosystemic	Low	Cog in the network

Source(s): Authors' own work

technical knowledge of the separation process, and the partner companies put up the dismantling operations:

There's a partnership with the recycling company: we give our partner the components that we don't need (after dismantling) [Case G].

We decided to go to a bigger recycler. [...], they don't extract the magnets. They have to go a step further (in their recycling process). [...], and we can inform them. [Case D]

Case F mainly carries out bridging strategies in terms of upstream partnerships with suppliers. The company is a magnet manufacturer holding a power position inside the SC because of technological competence, which makes its customers (e.g. OEMs) dependent on its supply of high-quality and customized magnets. The company has a relatively big presence in the market, and these elements allow the company to leverage long-term stable relationships with its suppliers ("We do have very long-standing relationships. Therefore, we don't change suppliers all the time", Case F). Case E instead is

investing massively to vertically integrate along the magnets' SC, both upstream with an exploration project in Greenland and downstream with a magnet-making plant to be launched in 2025 in Estonia and a recent acquisition of a magnet maker based in the UK. This allows the company to achieve a great deal of independence and make SC choices regarding prices, quality, or sustainability on its own ("[...]we have no choice but to vertically integrate", Case E).

4.1.2 Buffering strategies

Buffering strategies comprehend the creation of stock, increasing inventory to fight potential SC disruptions, spot purchases from different suppliers to not rely on single or few contracts, promoting recycling to create in-house sources of raw materials and focusing on product range and quality offered. Cases B and C, for example, as direct recyclers, have developed relationships that mainly revolve around single-spot purchases with the greatest possible number of suppliers to minimize shortage risks

and widen purchasing choices to face a disruption in supplying scrap magnets to their production processes.

We buy, like, everything (available). [Case B]

You have to work yourself on multiple sources to secure inputs because otherwise, you will never know (what can happen). We are buying as much as possible right now, even though we don't need it. [Case C]

Case F also developed a diversification strategy regarding suppliers to maximize its chances of supplier substitution and reduce dependence on single sources. Thus, the company can pursue both bridging and buffering strategies by diversifying the supplier base and, simultaneously, building long-term commercial relationships and leveraging its power position in the SC. In addition, companies that have manufacturing units pursue a buffering strategy by recycling magnet swarf and directly re-entering it into the production process.

If you are a magnet maker, you recycle your swarf. You don't need anyone else to do it. It's just part of running your business properly. [.]. You just throw it back to the metal-making step of the process. [Case E]

4.2 Strategic drivers

From a recurring exchange between the theoretical logic of the paper and the data, we identified institutional logic and autonomy as strategic drivers, meaning that in the context analysed, characterized by a strong dependence on scarce natural resources, the magnitude and direction assumed by these factors drive firms' strategic responses to SC issues.

4.2.1 Institutional logic

We found institutional logic to mainly revolve around two perspectives: the ecosystem perspective that goes towards building a competitive playground at the communitarian level, and the competitive perspective that emphasizes free competition as an individual firm. The ecosystem and competitive perspectives primarily differ for the stakeholders deemed as salient. The competitive firm gives utmost importance to market stakeholders, like customers, suppliers, employees and shareholders, shaping its SC strategic decisions on their requirements. Case E representative declares that the whole European magnets business unit was built to satisfy the requirements of some of their most important customers, who are European automotive companies asking their suppliers to diversify from China's critical raw materials and improve their Environmental, Social and Governance standards:

If our customers build a plant on the moon, we'd go to the moon with them. That's just the nature of our business. So, if our customers are asking for SC geographic optionality and high environmental, social and governance standards, [.]. and they want outside-of-China supply, well, we're building our out-of-China magnet facility. [Case E]

Instead, the ecosystem perspective promotes a vision of creating the SC geopolitical competitiveness through enforcing regulation at a communitarian level and creating alliances. Direct recycling companies (Cases B and C), for example, are lobbying to promote a European regulation for magnet scraps: they recognize that the fundamental but scarce resource needed for their production process is currently being exported outside the European Union and that only a focused regulatory action can invert this trend and diminish their reliance on such a scarce natural resource.

We (European Union) have to regulate the use of recycled material more in the manufacturing of new devices. We need to restrict the export of discarded magnets (towards third countries). [Case B]

I'm fighting as much as possible to keep the scraps in Europe and to avoid them in exporting. [Case C]

Case F looks at the European perspective as a big block for raw materials sourcing that should work jointly to promote the availability of primary and secondary materials for the whole European Union ecosystem of magnet makers.

The European Union block has so many other suppliers (of REEs) around the world that are looking for strategic partnerships in South America, Africa, Australia and North America. If we remain purely dependent on the Asian metals pricing, the whole business and the entire permanent magnet economy will be tuned by this. Having something that you can set against this would lead to a more robust system. [Case F]

The European Battery Alliance and the European Raw Materials Alliance initiatives might empirically represent such an ecosystem case at the European level. The first one, for example, is a valid example of how a negotiated environment inside the European Union can be set up to address a natural resource dependence issue. Critical raw materials companies envision the same role for the raw materials alliance.

We think that something like the European Battery Alliance should be a fundamental initiative for the European REEs industry, [.].and we had strong discussions. [.]. But it needs time[.] to convince all the European partners. [Case F]

Informed by NRDT, we deductively reconducted the institutional logic of the cases to a spectrum that ranges from the ecosystemic logic (informed by the ecosystem perspective) to the economizing logic (informed by the competitive perspective) based on the quotes reported and the questionnaires' results.

4.2.2 Autonomy

We found the concept of autonomy in the SC to be the most appropriate to describe the dynamics of adopting SC strategies. It determines how the firm can manage the dependence on the scarce natural resources in the SC as higher degrees of autonomy allow strategic choices that are otherwise not feasible. Autonomy is affected by the ability to integrate the SC, namely, how much the firm can overcome SC risk by gaining control over SC steps, by the size of the company's operations in the SC (i.e. in the permanent magnet business) and by the level of internalization of the SC, as in the context of analysis the geographical location of some of the operations revealed to be necessary.

The ability to integrate the SC was reported by almost all cases as a critical factor in obtaining autonomy in the value chain. Therefore, in a context where dependence on scarce natural resources is high, obtaining direct control over some or all the SC steps seems preferable to concentrating on a single step, as it allows the firm to avoid having multiple contracts with suppliers. It gives end customers a guarantee of the firm's reliability, thus marking an important and significant competitive advantage over less integrated firms.

So, we reposition [the company] as a magnet producer, being able to produce things with our recycled material. [The repositioning] was a game-changer because it gave us autonomy versus the Chinese supply chain, and being autonomous means that we can guarantee to our customers both sustainability [.]. and resiliency, meaning that if there are any shortages in terms of REEs, if there are any geopolitical issues with China, we can keep on producing. [Case C]

When it comes to price volatility control, vertical integration allows us essentially to have one contract on pricing with a final consumer, as opposed to having multiple contracts along the value chain, which have to be adjusted as the price of the underlying index of rare earth concentrates changes, that is essentially dominated by China. [Case E]

Size represents a requisite to sustainably carrying out certain SC steps. A key example is the magnet dismantling process, which requires both knowledge of the discarded magnets and their presence in waste from electronic equipment. It also requires a critical volume of recycling operations, which could make magnet dismantling economically feasible. Case D, for example, declares that it has built the magnet extraction knowledge inside the start-up by working on hard-disk drives and electric vehicle motors dismantling. Still, it decided to partner with a big recycling company as they were not able to put up a dismantling unit on their own:

We know how to extract the magnets. But it's too much to build it up (the extraction process) also for the high-tech startup. We're just a startup. [...] thus we decided to go to a bigger recycler. [Case D]

Internalization of the SC allows magnet firms to achieve autonomy concerning specific SC processes that are not possible to be carried out in specific geographies either because of the total unavailability of materials (e.g. absence of REEs' mining in Europe) or because of lack of the necessary regulatory permits and social licence to operate (e.g. radioactive waste treatment from the magnet separation process).

We can ship [from abroad] a non-radioactive product concentrate containing rare earths to our separation facility. The reason for that is that there's no place in Europe where you can get the social licence to operate and the permits to create essentially a graveyard for radioactive waste. [Case E]

We deductively reconducted the autonomy of the cases to a spectrum that ranges from low to high autonomy level based on the quotes reported and the questionnaires' results.

Figure 4 represents the configurations and strategies from Table 4 using *institutional logic* and *autonomy* as dimensions of analysis, providing a graphical representation of the above findings. It should be noted that the ecosystemic logic promotes bridging strategies, whereas the economizing one promotes buffering. In addition, as the firm's SC autonomy increases, the

company tends to adopt a mix of strategies comprising both bridging and buffering. This could happen because autonomy is related to power in external relationships, and an increase of power with customers and suppliers allows the firm to adopt bridging strategies as long-standing relationships or vertical integration, but at the same time, to leverage on spot purchases and stock whenever the scarce resources are needed.

4.3 Strategic levers

Strategic levers represent fields of action that firms might implement to manage dependence on scarce natural resources. Following Kalaitzi et al. (2018), we identified three leverages that influence SC management, namely, SS, DR and IR.

4.3.1 Supplier substitutability

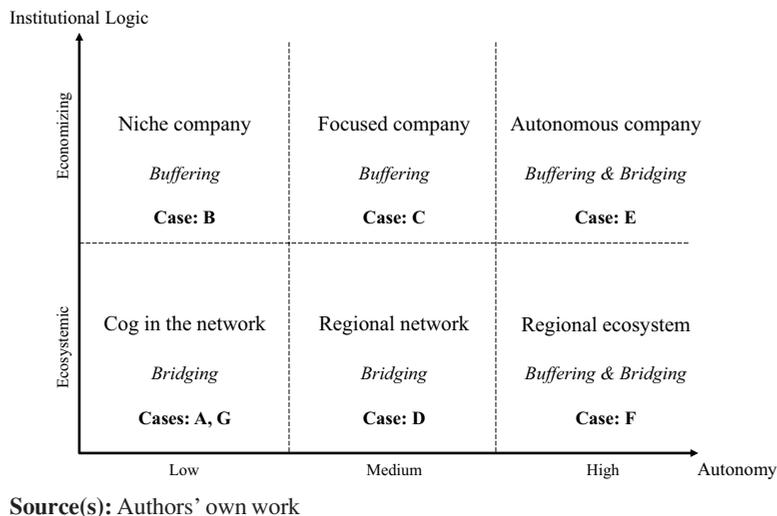
SS entails supplier diversification among different industries and geographies and the firm's overall number of active suppliers, as these elements influence the availability of suppliers and the chances of switching from one to another to avoid possible SC disruptions. Regarding the number of suppliers, firms in the REEs magnets are generally aware of the necessity of working with various sources of inputs to escape eventual out-of-stock of the scarce resource ("you have to work yourself on multiple sources to secure inputs because otherwise, you will never know", Case C). Moreover, to leverage SS, these sources should come from different countries and industries to reduce the most the risk of disruption due to geopolitical, market or physical unavailability of the resource:

That explains the geographical optionality: that we have multiple and stable upstream deals, both in Europe and out of Europe, that we can control and oversee. [Case E]

It's important not to rely on a single supplier. Every region in China has its own characteristics, and we have relationships with five active suppliers in China. We think that whenever something happens, it will not happen that all those five will stop delivering at the same time. [Case F]

SS lever is mainly adopted by companies that employ buffering strategies, as a higher number of diversified suppliers favours spot purchase behaviours and the creation of stock whenever supply is available on the market. For these reasons, this lever is mainly

Figure 4 Supply chain configurations, strategies and representative cases



adopted by cases B and C, coupled with an economizing logic, which emphasizes the attempt to minimize shortage risks and widen purchasing choices to the detriment of building long-term relationships.

4.3.2 Discretion over the resource

DR refers to the firm's overall control over the scarce natural resource in relation to a multitude of social, political, regulatory, technological and environmental factors. Institutional support was included as a discretion lever because in the REEs magnets industry, the support from a trusted institutional partner is the key to developing the complex technological processes that sustain magnets' recycling or separation ("almost all these companies (start-ups operating in REEs), [...] are spinoffs. So, they come from University Research Centers", Case B). Generally, the development of expertise to create a competitive playground has been heavily driven by the reliance on European projects and funding ("We developed the expertise (on magnet recycling) on our side in a (European) project and at the university in Potsdam", Case D). In addition, in some European countries such as France and Germany, there are attempts to create state-level systems that try to set up a level playing field for the companies operating in the country. Thus, there's evidence that the institutional support received influences the strategic choices of the REEs firm, contributing to their DR.

I'm happy and a bit jealous of the German companies and the support that they'll be getting. It's going a bit slower than France, but it's also the direction. [...] And it's coming together thanks to the work of other stakeholders in the industry. [Case E]

The state is giving subsidies. So, we have different companies trying to launch a business in this area. So, you know, Frenchness. [Case G]

The absence of clear regulation over dismantling, collecting and recycling e-waste appears to be a factor that limits the level of control over REEs. Therefore, all cases stated the necessity of strengthening European REEs magnets' regulation. In addition to the regulatory issues, the social licence to operate is also critical since the potential opposition from European local communities threatens the very life of a company operating in this sector (e.g. separation of REEs entails producing radioactive by-products):

If there is no infrastructure, the waste is sent maybe to someone else who burns it or someone else elsewhere, in another country that disassembles it. We don't know. The information is lost. But why? Because there's no law that obliges (to recycle the waste in-house). [Case A]

It's not just land use permits that need to be fast-tracked and included in the Critical Raw Materials Act legislation. It's a series of other permits as well, including storage and management and acceptance of naturally occurring radioactive materials because this is the real bottleneck. [Case E]

The geopolitical risk problem points in the same direction, as European companies are facing a structural disadvantage in terms of raw materials cost, which is around 30% on magnets. This factor limits the discretion that European companies have over REEs, and it highlights the role of regulation in bridging this entry gap. An envisaged intervention concerns the stock of secondary magnets, which should be forced to stay in the European Union, as it represents the main source of available raw materials directly possessed by European companies:

You're losing the stock of materials because you already bought them from China, and the primary sources are all coming from there. And then you lose

it again in this way because if you do not recycle, it will go to China [the secondary source]. [Case C]

Technological competence is a key element of competitiveness for all the cases, and it was the only factor that did not differ in the words of the informants depending on their institutional logic, autonomy or strategy adopted. This was also confirmed by the validation questionnaire. It thus appears as an entry-level factor for the highly technological REEs industry, and this justifies the widespread phenomenon of start-ups born from research centres and universities. In addition, talent localization is another factor that brings control over resources. When the company can create a hub of talents and make synergies among different processes and plants, then it is leveraging on DR:

The few talents (outside of China) are in Estonia. [...] Existing talent localization was the reason (for building the magnet-making plant in Estonia) as we wanted to make synergies by value chain proximity. [Case E]

Finally, SC sustainability is another factor that contributes to DR, as European companies tend to leverage it to respect European Environmental, Social and Governance standards, being in this way more attractive to OEMs, which need to respect such standards. Therefore, environmental sustainability could be seen as one of the main levers of differentiation with respect to Chinese magnet offering ("main strength is our process. It's, I think, the greenest way to recycle end of life magnet", Case D).

DR lever is used in all cases, at least for its component of technological competence. However, companies that have an ecosystemic logic tend to leverage more on factors pertaining to DR, such as regulation, geopolitical risk and SC sustainability (Cases G, D and F). Also, a higher degree of autonomy favours the chances to implement SC sustainability initiatives and lessen the geopolitical risk (Case E).

4.3.3 Importance of the resource

The IR is determined by the impact that the scarce resource has on the firm's performance. It is influenced by factors such as price volatility, cost and complexity of the production processes and availability of supply materials. Price volatility is a critical issue in the REEs magnets industry as commodities whose prices are anchored to market indices and mainly controlled by Asian markets. It is especially critical for secondary materials as a market does not exist for magnet scraps, and therefore, prices are not defined. These elements frame the heavy dependence on REEs as raw materials of European companies. However, some companies able to control price volatility (e.g. through vertical integration) have a powerful leverage to diminish the IR for them. In this regard, price volatility (control) represents a key determinant of the IR:

When it comes to price volatility control, vertical integration allows us to have (only) one contract with the final consumer, [...] to decouple from Chinese-set price volatility [Case E]

Similar logic can be applied to material availability. The absence of a real market for REEs makes it difficult not only to have stable prices but also to have a continuous flow of materials coming in to sustain the production process. The difficulty in getting both primary and secondary materials is shared among all the cases:

There's no continuous flow; they (suppliers) don't know when they're going to have materials. [Case B]

Most critical is to get the scrap. [...] Currently, we don't know exactly what scrap sources we will get. [Case D]

There were times that were extremely challenging with regard to finding the material, a lot of uncertainty in the market. [Case F]

We all know that we don't have enough secondary material so far on the markets. [Case G]

Regarding material availability, obtaining substantial autonomy from external suppliers through diversification (Case F) or vertical integration (Case E) seems the only way to strategically address the issue. In terms of the cost of magnets, firms declare the criticality of the magnets' dismantling operations, which are very complex and incur high costs related to developing the knowledge to identify the magnets inside the waste from electronic equipment, collect the waste, disassembly it and direct the components towards their best environmental and economic recovery (Case A). Finally, transportation costs can be an issue for scrap magnet supply, as when long distances must be covered, transportation costs could rise to an unsustainable share of the overall price of the scrap magnet:

Transportation (of secondary material) is very expensive. So having a supplier close to our company is better because of the transportation cost. We are buying waste, two euros per kilogram or less. So, it's a very low price compared to transport cost. [Case B]

IR is thus leveraged by cases that show a high degree of autonomy. However, it is critical for most cases with low autonomy, which struggle with the suppliers and are dependent upon an unstable market governed by Chinese-set price volatility.

Figure 5 resumes the considerations regarding the role that the three levers play in transitioning from one SC configuration to another, highlighting the main axis of increased adoption for each lever.

5. Discussion

This section discusses empirical findings in relation to extant literature to answer the research questions. We theorize how SC strategies are employed to manage dependence on scarce

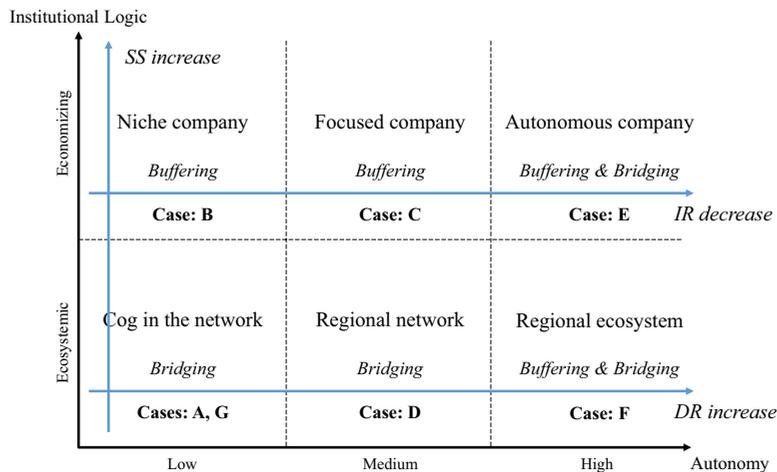
natural resources and the role of strategic drivers and levers in directing and sustaining the strategic solutions adopted by firms. The results of this study indicate that there's no evidence of an SC-wide strategy but of differentiated strategies that lead to the concurrent adoption of different SC solutions (Hilletoft, 2009). We argue that the uncertainty caused by NRS emphasizes the use of a typical set of strategies reflecting the need to address natural resource dependence and the difficulty in assessing the best strategic solution. Our results help disentangle the relationships between these strategies and typical strategic drivers and levers in this context.

5.1 The relationship between Supply chain strategies and strategic drivers

The study highlights that companies showing a low degree of autonomy and an ecosystemic institutional logic comply and balance pressures from different stakeholders, but they do not have specific leverages to act on (Cases A and G). When transitioning towards a more economizing logic, firms seem to adopt buffering strategies as the preferred way to position themselves in the SCs. This finding aligns with Bode et al. (2011), who posit an inverted U-shaped relationship between buffering and level of dependence, leading to a maximum rate of buffering adoption at a medium level of dependence, as in the niche company and focused company configurations. In line with NRDT, sample firms with an economizing logic adopt eco-development strategies that maximize the short-term chances of securing scarce natural resources. In an SC view, this translates into buffering actions to create a shield of slack resources to avoid supply disruptions.

The study also shows that companies assume power in their relationships with SC partners as autonomy increases. This fact complies with major RDT's literature demonstrating that size positively affects organizational power (Mezner and Nigh, 1995; Van den Bosch and Van Riel, 1998); however, in our conceptualization of strategic drivers, size is the internal factor that contributes to autonomy, in addition to the more externally focused ability to integrate the SC and degree of

Figure 5 Strategic levers effect on supply chain configurations and strategies



Source(s): Authors' own work

internationalization of the SC. In this view, the regional network solution (Case D) represents an ecosystemic setting where the players bargain between themselves to form stable relationships and create independence from third parties. If the network is particularly extended and integrated, it can lead to a proper ecosystem or an alliance that becomes part of the institutional context and has the power to influence norms and values (Case F). Therefore, organizations adopt bridging strategies by forming close interrelationships to diminish the external uncertainty in the market (Bode *et al.*, 2011).

On the contrary, in the economizing logic, firms open their business to different markets whenever needed to avoid institutional pressures. As autonomy gets higher, the firm can leverage its power position to challenge some institutional norms without excessive concerns about being pushed out of the market for the power position it holds (Mezner and Nigh, 1995). In such a case, RDT literature states that companies tend to adopt a buffering strategy (Mezner and Nigh, 1995; Roundy and Bayer, 2019; Bode *et al.*, 2011), as it happens in the focused company configuration (Case C). In addition, our study indicates that bridging strategies are used simultaneously in an attempt to manage NRS with differentiated strategies (Hilletoft, 2009). This happens for Case F, which is diversifying the supplier base to reduce SC disruption risk while simultaneously having the power to maintain long-term relationships with suppliers. Case E is even more representative, as it pursues a bridging strategy (downstream and upstream integration) to reach autonomy on the market and obtain control over price and quantities, an outcome that is usually achieved through buffering (Kalaitzi *et al.*, 2018). As a matter of fact, under the threats of NRS and the uncertainty it creates, companies find it difficult and riskier to make investments and pursue innovation (e.g. recycling, closed-loop SC, eco-design of products) with their resources. Thus, the interplay between bridging and buffering strategies becomes stronger (Kalaitzi *et al.*, 2019; Hillman *et al.*, 2009; Bell *et al.*, 2013).

5.2 The relationship between strategic levers and supply chain strategies

Our findings show that adopting different SC solutions to manage dependence on scarce natural resources leads to acting on different RDT leverages (IR vs SS vs DR). SC solutions, where SS is the preferred lever adopted, bring the firm to diversify the suppliers' base to prevent SC disruption, leveraging the availability of alternative suppliers and the low switching costs. However, this can lead to the implementation of both buffering and bridging strategies. In such a case, analysing the importance of resource scarcity for the firm offers key insights to determine the strategic choice towards bridging or buffering.

IR should be intended as preferable if low, as it represents the magnitude by which the scarce resource affects the firm's performance. Literature associates a high IR with the adoption of buffering strategies (Mezner and Nigh, 1995; Van den Bosch and Van Riel, 1998; Kalaitzi *et al.*, 2018). Our study adds that when IR is scarcely affecting the firm, it can pursue buffering and bridging at the same time, leveraging both IR and SS. In fact, in the niche company and focused company configurations, Cases B and C perform a strict buffering strategy, supplying and accumulating scrap magnets whenever available from their suppliers because they are not controlling

the availability of supply, and an eventual disruption would heavily influence their financial outcomes. Instead, case E has gained greater control over prices and quantities of its input resources by carrying out a bridging strategy through vertical integration and can leverage on a low IR with its customers, which asks for price volatility control and sourcing geographical optionality that only case E can guarantee. In network configurations, the main actionable lever to manage dependence is DR, as discretion mainly arises at a policy level, particularly in critical raw materials contexts where geopolitical struggles heavily influence the business environment.

The findings about the strategic levers bring novelty to the NRDT literature. Kalaitzi *et al.* (2018) concluded that both SS and DR lessen firms' buffering and bridging activities. Our evidence integrates these findings, showing that DR may positively influence the adoption of bridging strategies in a strong ecosystem orientation. At the same time, a higher SS may lead to greater adoption of buffering in a strong economizing orientation. The institutional perspective, rather than technological, is thus the key to explaining these diverging findings. An ecosystemic logic is associated with SC configurations that aim at building cohesive networks where DR can be favourably leveraged through bridging strategies with network partners. As a representative from Case F explains, in the REE industry:

It's not a technological barrier. [...] Again, the extremely fierce competition from the Chinese suppliers enabled them to take over the market and invest a lot in development. [...] (they have) cheaper costs because they have subsidies, cheaper labour costs, and so on. How to break through that, I struggle honestly

6. Conclusions

The critical raw materials landscape in Europe is threatened by a significant dependence on third countries for imports and by an ever-growing demand related to the use of these materials in green technologies. The SC delocalization trend in the past years has led to the dismissal of nearly all operations in most critical raw materials industries (Wagner and Bode, 2008), but in the past few years, driven by political and regulatory support (e.g. the Critical Raw Materials Act), new business initiatives are emerging at several SC steps to sustain European resilience over critical raw materials. This paper disentangles SC dynamics to manage dependence over scarce natural resources in this context. We drew on NRDT and RDT, analysing the adoption of buffering and bridging strategies depending on the institutional logic and the autonomy of the firm in the SC as strategic drivers. Then, we examined how strategic levers (IR, SS and DR) can be used within the identified SC strategies to manage external dependencies on scarce resources. In addition, we analysed their role in facilitating transitions between strategic solutions, highlighting the primary axes of leverage and growth.

To do this, we carried out seven case studies belonging to the REEs magnets European industry, analysing their SC positioning, strategies, processes, suppliers and customers relationships and prominent business criticalities.

6.1 Theoretical contributions

This study offers evidence of real-world cases to the growing body of research on NRS implications for the firm (Tashman, 2021;

Dias *et al.*, 2022; de Abreu *et al.*, 2017; Galbreath *et al.*, 2020; Tashman and Rivera, 2016). The study investigates the case of REEs magnets in Europe, a natural resource that is non-renewable and scarce at a non-local level, representing a novel context of analysis for NRDT where the SC-wide perspective and the focus on external relationships and collaborations assume utmost importance. The theoretical contributions of the paper indeed concern both SC and NRS literature.

Firstly, this paper links the adoption of diversified SC management strategies when firms manage dependence on a naturally scarce resource (Hilletofth, 2009) to six different SC configurations that differ in terms of institutional logic, autonomy and strategic solutions adopted. The paper contributes to NRDT literature, showing how and under what conditions firms that depend upon natural resources and face uncertainty concerning those resources form relationships with others to obtain these resources or pursue vertical integration (Sarkis *et al.*, 2011; Carter and Rogers, 2008). In particular, the study proposes that in sectors where natural resources are scarce and competition becomes intense (López-Gamero *et al.*, 2011), firms adopt buffering strategies to shield the firm even from the partnering organizations. By doing that, we advance NRS and SC literature by showing that NRS favours the interplay between bridging and buffering strategies, as companies are more prone to collaborate along the SC to reduce uncertainty while simultaneously creating their own safeguard against possible SC disruptions.

Secondly, we elaborate on NRDT by extending the perspective of strategic responses to NRS (Tashman, 2021) at an SC level. We introduce two drivers of SC strategic responses to NRS: *institutional logic* and *autonomy*. The first one, taken from NRDT, is deployed as economizing and ecosystemic logic, highlighting the institutional orientation in the firm's external relationships. The ecosystemic logic not only resonates with the "ecologizing" perspective of the NRDT in its emphasis on transforming environmental governance institutions to promote sustainability but also enriches this perspective by highlighting the critical role of SC dynamics in achieving sustainable use and equitable distribution of scarce natural resources at the ecosystem level – specifically within the European Union, as examined in this study. Autonomy, instead, extends the established finding of RDT that firm size positively influences power in external relationships (Meznar and Nigh, 1995; Van den Bosch and Van Riel, 1998). At the SC level, this concept is proposed to include both SC size and its degree of integration and internationalization, recognizing these factors as key elements influencing power in external relationships.

Thirdly, we fill a gap in RDT by clarifying the role of strategic levers in managing SCs under NRS. We integrated Kalaitzi *et al.*'s (2018) findings by revealing how the DR and SS levers combine with institutional logic, suggesting that DR favours bridging, mainly when the firm adopts an ecosystemic logic, whereas SS leads to buffering, mainly when the firm adopts an economizing logic.

Overall, our conceptualization of the effect of strategic levers on SC configurations and strategies systematically shows how IR, SS and DR combine with the adoption of buffering and bridging strategies in different SC solutions, contributing to the interface of NRDT and SC management.

6.2 Managerial contributions

This study provides important managerial implications for SC managers in developing strategies to cope with NRS. Firstly, this paper details six strategic configurations that SC managers operating in industries under NRS threat can refer to. Particularly, the paper's framing is based on the consequential interplay between strategic drivers, strategies and strategic levers and can be used as a strategy-implementation guiding framework. Managers can consider the dominant institutional logic and the degree of autonomy of their firm in the SC to frame their positioning with reference to Figure 4 and devise their strategic choices. In addition, the paper also shows the levers that SC managers should act to leverage their configurations. From a broader perspective, managers can use the levers to transition from one configuration to another, following the main axis of growth of each lever (Figure 5) and reaching the envisioned positioning in terms of strategic drivers. Moreover, to our knowledge, this research is the first to target critical raw materials' SC strategies. We contribute by showing how totally different businesses, with differentiated SC strategies, from start-ups to multinational companies, can co-exist. Based on the findings of this paper, we recommend to critical raw materials practitioners, particularly from start-ups, that bridging strategies consisting of establishing long-term partnerships can be preferable to survive in the long term. We suggest strategically focusing on three factors: price volatility control, localization of technological talent and sustainability of the SC. We also recommend sustained policy intervention and regulatory support, as they have been shown to be indispensable in establishing a European-level playing field for REE magnets. Finally, we argue that our research can be of interest to practitioners involved in other industries suffering similar conditions of dependence on NRS and institutional struggles, such as the automotive industry in relation to REEs magnets but also cobalt and lithium, among the other critical raw materials necessary for the energy transition, and the electronic industry with regard to its dependence on semi-conductors.

6.3 Limitations and future research

This study does not come without limitations as with any scientific work. In fact, our phenomenon-based approach prioritises the understanding of the complexity of NRS-related strategies in a meaningful setting over the immediate generation of widely generalizable theoretical contributions. Consequently, firstly, the reliance of our study on information from organizations willing to participate in the research might hinder the external validity of the findings. Thus, the viewpoints of those who did not respond are not accounted for in this paper, potentially limiting the conclusions drawn and prompting further investigation. However, we tackled this limitation through two methods. Initially, we ensured diversity within our interview pool, welcoming companies of different sizes, SC positions and integration levels, trying to cover as much of the REEs magnets industry as possible (Grabs and Garrett, 2023). We also complemented the interviews with direct observation, with a validation questionnaire, and through analysis of secondary sources to encompass alternative perspectives. Secondly, our insights derive from examining case studies coming from a single sector. While we hypothesize that

the presented insights reveal general trends that theoretically apply to all critical raw materials industries, this hypothesis should be tested in future research regarding critical raw materials' SCs, which is not adequately developed despite the key role of critical raw materials in the energy transition. For example, the positioning of sustainability as a resource dependence, envisioned by [Schnittfeld and Busch \(2016\)](#), should be studied in critical raw materials' SCs as exposed to huge threats to the environment and the people ([Massari and Ruberti, 2013](#); [Golev et al., 2014](#)). Moreover, to sample only organizations facing REEs scarcity issues, our sampling strategy introduced a significant degree of heterogeneity with regard to other firms' dimensions, such as size, maturity and SC positioning. In certain cases, difficulties in conclusively spotting the sources of the differences across the cases call for additional investigation to further support the generalizability of the findings. Besides these identified needs for further research, among the promising avenues arising from our study, and given the importance of institutional mechanisms in this field, we argue that a valuable research direction would involve analysing the enabling mechanisms among organizations and institutions to foster alliances or ecosystems. Examples of such initiatives might include, for instance, the European Battery Alliance and the European Raw Materials Alliance.

Notes

- 1 The extraction stage was not covered because of the current absence of REEs mining in Europe.
- 2 See the interview protocol in [Appendix 1 Table A1](#) for more details regarding the questions and their connection with the theoretical dimensions studied.
- 3 The data structure was reviewed during the peer-review phase of the paper, as a response to the reviewers' comments. Also at this stage, a collaborative effort among the authors was chosen to reconcile the codes and reach an agreement on the updated data structure.

References

- Bell, J.E., Mollenkopf, D.A. and Stolze, H.J. (2013), "Natural resource scarcity and the closed-loop supply chain: a resource-advantage view", *International Journal of Physical Distribution & Logistics Management*, Vol. 43 Nos 5/6, pp. 351-379.
- Bell, J.E., Autry, C.W., Mollenkopf, D.A. and Thornton, L.M. (2012), "A natural resource scarcity typology: theoretical foundations and strategic implications for supply chain management", *Journal of Business Logistics*, Vol. 33 No. 2, pp. 158-166.
- Berchicci, L. and King, A. (2007), "11 postcards from the edge: a review of the business and environment literature", *Academy of Management Annals*, Vol. 1 No. 1, pp. 513-547.
- Bergmann, A., Stechemesser, K. and Guenther, E. (2016), "Natural resource dependence theory: impacts of extreme weather events on organizations", *Journal of Business Research*, Vol. 69 No. 4, pp. 1361-1366.
- Bode, C., Wagner, S.M., Petersen, K.J. and Ellram, L.M. (2011), "Understanding responses to supply chain disruptions: insights from information processing and resource dependence perspectives", *Academy of Management Journal*, Vol. 54 No. 4, pp. 833-856.
- Bowen, F.E., Bansal, P. and Slawinski, N. (2018), "Scale matters: the scale of environmental issues in corporate collective actions", *Strategic Management Journal*, Vol. 39 No. 5, pp. 1411-1436.
- Caniëls, M.C. and Gelderman, C.J. (2007), "Power and interdependence in buyer supplier relationships: a purchasing portfolio approach", *Industrial Marketing Management*, Vol. 36 No. 2, pp. 219-229.
- Carter, C.R. and Rogers, D.S. (2008), "A framework of sustainable supply chain management: moving toward new theory", *International Journal of Physical Distribution & Logistics Management*, Vol. 38 No. 5, pp. 360-387.
- CEPS (2022), "Developing a supply chain for recycled rare earth permanent magnets in the EU", Brussels, available at: <https://www.ceps.eu/ceps-publications/developing-a-supply-chain-for-recycled-rare-earth-permanent-magnets-in-the-eu/>
- Chapin, F.S., Kofinas, G.P. and Folke, C. (Eds) (2009), *Principles of Ecosystem Stewardship: resilience-Based Natural Resource Management in a Changing World*, Springer Science & Business Media.
- Cole, R. (2024), "Inter-rater reliability methods in qualitative case study research", *Sociological Methods & Research*, Vol. 53 No. 4, pp. 1944-1975.
- de Abreu, M.C.S., de Freitas, A.R.P. and Rebouças, S.M.D.P. (2017), "Conceptual model for corporate climate change strategy development: empirical evidence from the energy sector", *Journal of Cleaner Production*, Vol. 165, pp. 382-392.
- Dias, C., Rodrigues, R.G. and Ferreira, J.J. (2022), "Linking natural resources and performance of small agricultural businesses: do entrepreneurial orientation and environmental sustainability orientation matter?", *Sustainable Development*, Vol. 30 No. 4, pp. 713-725.
- Etikan, I., Musa, S.A. and Alkassim, R.S. (2016), "Comparison of convenience sampling and purposive sampling", *American Journal of Theoretical and Applied Statistics*, Vol. 5 No. 1, pp. 1-4.
- European Commission (2023a), "Critical raw materials: ensuring secure and sustainable supply chains for EU's green and digital future", Brussels, available at: https://ec.europa.eu/commission/presscorner/api/files/document/print/en/ip_23_1661/IP_23_1661_EN.pdf
- European Commission (2023b), "Study on the critical raw materials for the EU 2023 – final report", available at: https://single-market-economy.ec.europa.eu/publications/study-critical-raw-materials-eu-2023-final-report_en
- Galbreath, J., Tisch, D., Quaddus, M. and Rabbanee, F. (2020), "The impact of climate change on firm adaptation: the case of the wine industry", *International Journal of Wine Business Research*, Vol. 32 No. 3, pp. 373-389.
- Gioia, D.A., Corley, K.G. and Hamilton, A.L. (2013), "Seeking qualitative rigor in inductive research: notes on the Gioia methodology", *Organizational Research Methods*, Vol. 16 No. 1, pp. 15-31.
- Golev, A., Scott, M., Erskine, P.D., Ali, S.H. and Ballantyne, G.R. (2014), "Rare earths supply chains: current status,

- constraints and opportunities”, *Resources Policy*, Vol. 41, pp. 52-59.
- Grabs, J. and Garrett, R.D. (2023), “Goal-based private sustainability governance and its paradoxes in the Indonesian palm oil sector”, *Journal of Business Ethics*, Vol. 188 No. 3, pp. 467-507.
- Hilletofth, P. (2009), “How to develop a differentiated supply chain strategy”, *Industrial Management & Data Systems*, Vol. 109 No. 1, pp. 16-33.
- Hillman, A.J., Withers, M.C. and Collins, B.J. (2009), “Resource dependence theory: a review”, *Journal of Management*, Vol. 35 No. 6, pp. 1404-1427.
- Hoffman, A. and Jennings, P.D. (2021), “Institutional-political scenarios for anthropocene society”, *Business & Society*, Vol. 60 No. 1, pp. 57-94.
- International Energy Agency (2021), “The role of critical minerals in clean energy transitions”, available at: www.iea.org/data-and-statistics/data-product/the-role-of-critical-minerals-in-clean-energy-transitions-2
- Kalaizti, D., Matopoulos, A., Bourlakis, M. and Tate, W. (2018), “Supply chain strategies in an era of natural resource scarcity”, *International Journal of Operations & Production Management*, Vol. 38 No. 3, pp. 784-809.
- Kalaizti, D., Matopoulos, A., Bourlakis, M. and Tate, W. (2019), “Supply chains under resource pressure: strategies for improving resource efficiency and competitive advantage”, *International Journal of Operations & Production Management*, Vol. 39 No. 12, pp. 1323-1354.
- Ketokivi, M. and Choi, T. (2014), “Renaissance of case research as a scientific method”, *Journal of Operations Management*, Vol. 32 No. 5, pp. 232-240.
- López-Gamero, M.D., Molina-Azorin, J.F. and Claver-Cortés, E. (2011), “Environmental uncertainty and environmental management perception: a multiple case study”, *Journal of Business Research*, Vol. 64 No. 4, pp. 427-435.
- Lumineau, F., Kong, D.T. and Dries, N. (2025), “A roadmap for navigating phenomenon-based research in management”, *Journal of Management*, Vol. 51 No. 2, pp. 505-517.
- McGinnis, M. and Ostrom, E. (2014), “Social-ecological system framework: initial changes and continuing challenges”, *Ecology and Society*, Vol. 19 No. 2, p. 30.
- Manhart, P., Summers, J.K. and Blackhurst, J. (2020), “A meta-analytic review of supply chain risk management: assessing buffering and bridging strategies and firm performance”, *Journal of Supply Chain Management*, Vol. 56 No. 3, pp. 66-87.
- Massari, S. and Ruberti, M. (2013), “Rare earth elements as critical raw materials: focus on international markets and future strategies”, *Resources Policy*, Vol. 38 No. 1, pp. 36-43.
- Meznar, M.B. and Nigh, D. (1995), “Buffer or bridge? Environmental and organizational determinants of public affairs activities in American firms”, *Academy of Management Journal*, Vol. 38 No. 4, pp. 975-996.

- Mishra, D., Sharma, R.R.K., Kumar, S. and Dubey, R. (2016), “Bridging and buffering: strategies for mitigating supply risk and improving supply chain performance”, *International Journal of Production Economics*, Vol. 180, pp. 183-197.
- Oliver, C. (1991), “Strategic responses to institutional processes”, *The Academy of Management Review*, Vol. 16 No. 1, pp. 145-179.
- Ostrom, E. (1999), “Coping with tragedies of the commons”, *Annual Review of Political Science*, Vol. 2 No. 1, pp. 493-535.
- Pfeffer, J. and Salancik, G.R. (2003), *The External Control of Organizations: A Resource Dependence Perspective*, Stanford University Press, Stanford, CA.
- Ridder, H.G. (2017), “The theory contribution of case study research designs”, *Business Research*, Vol. 10 No. 2, pp. 281-305.
- Rockström, J., Steffen, W., Noone, K., Persson, Å., Chapin, F.S., Lambin, E. and Foley, J. (2009), “Planetary boundaries: exploring the safe operating space for humanity”, *Ecology and Society*, Vol. 14 No. 2.
- Roundy, P.T. and Bayer, M.A. (2019), “To bridge or buffer? A resource dependence theory of nascent entrepreneurial ecosystems”, *Journal of Entrepreneurship in Emerging Economies*, Vol. 11 No. 4, pp. 550-575.
- Sarkis, J., Zhu, Q. and Lai, K.H. (2011), “An organizational theoretic review of green supply chain management literature”, *International Journal of Production Economics*, Vol. 130 No. 1, pp. 1-15.
- Schnittfeld, N.L. and Busch, T. (2016), “Sustainability management within supply chains—a resource dependence view”, *Business Strategy and the Environment*, Vol. 25 No. 5, pp. 337-354.
- Tashman, P. (2021), “A natural resource dependence perspective of the firm: how and why firms manage natural resource scarcity”, *Business & Society*, Vol. 60 No. 6, pp. 1279-1311.
- Tashman, P. and Rivera, J. (2016), “Ecological uncertainty, adaptation, and mitigation in the US ski resort industry: managing resource dependence and institutional pressures”, *Strategic Management Journal*, Vol. 37 No. 7, pp. 1507-1525.
- Van den Bosch, F.A. and Van Riel, C.B. (1998), “Buffering and bridging as environmental strategies of firms”, *Business Strategy and the Environment*, Vol. 7 No. 1, pp. 24-31.
- Wagner, S.M. and Bode, C. (2008), “An empirical examination of supply chain performance along several dimensions of risk”, *Journal of Business Logistics*, Vol. 29 No. 1, pp. 307-325.
- Wang, H., Choi, J. and Li, J. (2008), “Too little or too much? Untangling the relationship between corporate philanthropy and firm financial performance”, *Organization Science*, Vol. 19 No. 1, pp. 143-159.
- Wry, T., Cobb, J.A. and Aldrich, H.E. (2013), “More than a metaphor: assessing the historical legacy of resource dependence and its contemporary promise as a theory of environmental complexity”, *Academy of Management Annals*, Vol. 7 No. 1, pp. 441-488.
- Yin, R.K. (2014), “Case study research”, *Design and Methods*, 5th ed., Sage Publications, London, Thousand Oaks.
- York, J., Hargrave, T. and Pacheco, D. (2016), “Converging winds: logic hybridization in the Colorado wind energy field”, *Academy of Management Journal*, Vol. 59 No. 2, pp. 579-610.

Appendix 1

Table A1 Interview protocol

No.	Questions	Notes	Connection to study variables
1	Introduction to the study, consent for recording, etc		
2	The interviewee introduces himself and his background	Ask about field of study, work sector, current role in the company and how long they have been working there	
A	<i>Supply chain configuration and relationships</i>		
3	Presentation of the organization which the interviewee work in Which is the main activity of the firm (with REEs)? Which kind of technological process(es) do you operate?	Ask characteristics of the firm they work in: year of foundation, size, countries they operate in. Then ask about the technological process(es) operated with reference to REEs magnets supply chain	
4	What is the position/role of your organization in the REE supply chain? Which SC stages do you cover?	Ask what their position in the supply chain is, and how many stages are covered by the firm	Autonomy/level of integration in the SC
5	Which materials do you input? Who are your suppliers? Which percentage of suppliers come from outside of China? Which kind of relationships do you have with suppliers? Which types of contracts? Are there differences in suppliers' management between Chinese and non-Chinese suppliers?	Supply side: ask about who are the suppliers of the firm and the typologies of relationships held with them (long-term vs spot, single sourcing vs multiple sourcing, etc.). Focus on China to understand the level of independence from Chinese inputs	Strategic levers (IR, SS, DR)
6	Which are the final outputs of your production process? Who are your customers? Which kind of relationships do you have with customers? Which types of contracts?	Customer side: ask about who are the customers of the firm and the typologies of relationships held with them	Strategic levers (IR, SS, DR)
B	<i>REE dependence level and supply chain NRS strategies</i>		
7	What do you see as the main pressures and reasons to manage the issue of REEs scarcity effectively in your firm that could affect your supply chain and product portfolio?	Adapted from Kalaitzi et al. (2019) . Focus on scarcity's criticalities, its causes and consequences and the actors who drive pressures	
8	Please concentrate on a recent REEs scarcity issue (during the past five years), can you describe the main reason(s) of the scarcity? Which strategies did you use to cope with it?	Strategies for overcoming natural resource scarcity. Understand how these measures emerged: top-down or bottom-up approach, collaboration with suppliers or focal firms, etc. Determine whether the company had already developed the capacity to manage scarcity related to the supply of other raw materials	Buffering and bridging strategies
9	Which leverages of competitiveness does the firm rely on to cope with REEs scarcity and stay on the market?	Make reference to the following dimensions if the interviewee is not addressing them: <ul style="list-style-type: none"> • Price • Quality • Technology and competence • Regulation • Sustainability of the SC (including recycling) • Supplier diversification • Partnerships 	Strategic levers (IR, SS, DR)
C	<i>Institutional support</i>		
10	Which are the most important stakeholders for the firm? How does the firm take into consideration their requirements? Are the firm involved in projects/ partnerships with the government, the European Commission, a university or other public actors?	Ask about relationships with institutional actors and the activities carried out with them. Focus on the strength of the institutional ties of the firm	Institutional logic

Note(s): The protocol is intended to be semi-structured and has been adjusted to the specific case of each interview to maximize the collection of useful and appropriate information

Source(s): Authors' own work

Appendix 2

Table A2 Coding tables

2° order themes	1° order themes	Supporting quotes and evidence	
1. Strategies			
Bridging	Building partnerships (downstream)	<p>"We are not currently evaluating other supply streams (besides electronics manufacturers) as the priority is on the control of the streams [A]"</p> <p>"We are in deeper contacts with a big recycler here in Germany, with also a memorandum of understanding signed with them. So, we will get our material from them [D]"</p> <p>"We have a joint venture in Beijing with some from the Samsung group there. And there I have a board function. But we have many joint ventures there [F]"</p> <p>"In Europe we are searching for a strategic partner. This could be one of the OEMs. This could be an industrial partner [F]"</p> <p>"We have partnership with car manufacturers, to secure their supply in rare earth material. There's a partnership with the recycling company: we give our partner the components that we don't need (after dismantling) [G]"</p>	
	Exchanging information	<p>"The consortium is working with technology manufacturers to investigate the actual presence of rare earth elements in their products. The availability of internal streams within a given company ensures a controlled flow of resources [A]"</p> <p>"We are certain that inside there is neodymium, when we have the certainty from the manufacturer. For this reason, we were confident that we could contact other producers and now we are moving in this direction [A]"</p> <p>"Recycling companies have access to different devices that contain a permanent magnet, but then you have to collaborate with them in order to help them to how to separate the permanent magnet [B]"</p> <p>"We decided to go to a bigger recycler. They have the components but currently they don't extract the magnets. They must go a step further. They just need to make an additional step in the separation of the components, and we can inform them [D]"</p>	
	Building partnerships and long-standing relationships (upstream)	<p>"We do have very long-standing relationships, we don't change suppliers all the time. (...) For us it's really important to have a long-term supply agreement with a partner [F]"</p> <p>"We had to establish very close contacts with our equipment suppliers as a lot of the technology moved to China [F]"</p> <p>"If we want to be successful, we cannot make that on-the-spot decision. We have to think about partnership and long-term partnership (talking about suppliers) [C]"</p>	
	Vertical integration (upstream and downstream)	<p>"For us to decouple from the Chinese set price volatility, we have no choice but to vertically integrate [E]"</p> <p>Case E is investing massively in order to vertically integrate, both upstream (Greenland exploration project) and downstream (magnet making plant to be launched in 2025 in Estonia; recent acquisition of a magnet maker based in UK) [company data and public news]</p> <p>"So, we reposition (the company) as a magnet producer, being able to produce things with our own recycled material. (the repositioning) was a game-changer because it gave us autonomy versus the Chinese supply chain [C]"</p>	
	Buffering	Improving product range and quality	<p>"Almost 100% of our products are specifically designed products, are customer specific and we don't have any off the shelf catalog magnets. The value that we provide to our customers is the quality and the variety of the products [F]"</p> <p>"We can value to our clients that it's green (the magnets) and (...) the quality [G]"</p>
		Stock building	<p>"We buy, like, everything (available) [B]"</p> <p>"We are buying as much as possible right now, even though we don't need it [C]"</p>
		Recycling	<p>"If you are a magnet maker, you recycle your own swarf, you don't need anyone else to do it. It's just part of running your business properly. You literally just take the swarf that hasn't been contaminated. You don't have to deal with it. You just throw it back to the metal making step of the process [E]"</p> <p>"We are doing a total recycling when we have scrap during the production [F]"</p>
		Spot purchasing	<p>"When they (suppliers) collect around 100 kilograms they call me and say that I can come and bring them. It's not like a real agreement [B]"</p> <p>"The majority is spot purchase. And the reasons why we increase the number of suppliers is basically if new market entrants come up, we are interested to check quality and prices and we start working with them [F]"</p>
	2. Strategic drivers		
	Institutional logic	Ecosystem perspective	<p>"We (European Union) have to regulate more in the use of recycled material in the manufacturing of new devices. We need to restrict that export of discarded magnets (towards third countries) [B]"</p> <p>"I'm fighting as much as possible to keep the scraps in Europe and to avoid them in exporting [C]"</p> <p>"I don't think it's wise if the EU just focused on one block for the raw materials, the EU block. There are so many other sources outside in this world, that look for strategic partnerships, South America, Africa, Australia, North America. Because if we are purely dependent on the Asian metals pricing, the whole business, the entire permanent magnet economies can be tuned by this. If you have something that you can set against this, this would lead to a more robust system [F]"</p> <p>"(there are) good projects that look at how to disassemble magnets. I honestly can't judge if they're economical at the moment. It's maybe too early. But let's say we find a way to extract it in an economic fashion. Then it's just a hydro metallurgical route to have the metals again. So this would be definitely a strong value proposition from the European Union [F]"</p> <p>"We think that something as the European Battery Alliance should be a must for the European REEs industry and we had strong discussions to convince German ministeria together with heavy partners like Bosch, Siemens, Schaeffler. But it needs time to come from Berlin, to Brussels and to convince all the European partners [F]"</p> <p>"The short loop technology is more complementary (with us). The two business models can live together. As I mentioned, the state is giving subsidies. So we have different companies trying to launch a business on this area. So, you know, Frenchness. But we are talking with them a lot [G]"</p>
Competitive perspective		<p>"The majority (of secondary feedstock) will be electric vehicle motors. And then the second largest category will be offshore wind turbine. The rest is certainly uneconomical to even bother thinking about. What are you going to do, extract five grams of rare earth magnet from a hard disk drive? The effort and the money that the EU puts into getting that magnet, whether it's manual, robotic or whatever, well, you'll never make back that money [E]"</p> <p>"If our customers build a plant in the moon, we'd go to the moon with them. That's just the nature of our business. So, if our</p>	

(continued)

Table A2

2° order themes	1° order themes	Supporting quotes and evidence
Autonomy	Ability to integrate the supply chain	customers are asking for supply chain geographic optionality and high ESG standards and they're building motor making facilities for electric vehicles in Europe and they want outside of China supply, well we're building our out of China magnet facility [E] "The most important stakeholders are the customers, the suppliers, the employees, our shareholders, it's not so much the state, to be honest [F]" "Being autonomous means that we can guarantee to our customers both the sustainability (...) and the resiliency, meaning that if there are any shortages in terms of REEs, if there is any geopolitical issue with China, we can keep on producing [C]" "We can build up the complete value chain (of magnet recycling). With the expertise in the extraction of several components, with the recycling process, with the powder treatment, with the magnet manufacturing we built up the complete value chain [D]" "when it comes to price volatility control, vertical integration allows us essentially to have one contract on pricing with a final consumer, as opposed to having multiple contracts along the value chain, which have to be adjusted as the price of the underlying index of rare earth concentrate changes, that is essentially dominated by China [E]" "If you want an out-of-China supply chain, you have to adjust to the reality that you have to do things on your own [E]"
	Size	"We know how to extract the magnets. But it's too much to build it up also for the high-tech startup. We're just a startup [D]" "We have other competitors in the United States, like a huge company. They have closed an investment round of \$75 million to build like a big factory of recycling permanent magnet"
	Supply chain internationalization	Cases B and C reported the scaling in terms of tonnes per year processed of magnets as a key factor to stay in the market "With part (of the supply chain) coming from the United States, (...) we are able to ship a non-radioactive product concentrates containing rare earths to our separation facility. The reason for that is that there's no place in Europe, where you can actually get the social licence and the permits to create essentially a graveyard for radioactive waste [E]" "The first strategic step was to have unification with the American side. This is a big for us, as this opens the option to have a mine outside China and get material from non-Chinese supplier [F]"
	3. Strategic levers Supplier substitutability	Supplier diversification
Discretion over the resource	Number of suppliers	"It's important to do not rely on a single supplier. Every region in China has its different characteristics and we have relationships with five active suppliers in China. We think that whenever something happens this will be not the issue that all of those five will stop delivering at the same time [F]" "five (suppliers) on average. But sometimes we reduce our number of suppliers. Sometimes we increase it a little bit [F]" "we have around 4 or 5 different suppliers, and they are basically magnet manufacturers or electric motor manufacturers, or maybe companies who treat or manage industrial waste [B]"
	Institutional support	"we decided to launch this company together with our research center. (...) almost all these companies (startups operating in REEs), are spinoffs. So they come from University Research Centers" [B] → Cases B, C and D were born as spin-off companies from university's research centers "we developed the expertise (on magnet recycling) on our side in a (European) project and at the university in Potsdam [D]" "we needed a jurisdiction that would kind of make it a national cause for them and work with us to just get permits, get everything, including some form of government funding support [E]" "(for the radioactive permits) we need to start this whole regulatory odyssey with the government of Estonia, which will take years [E]" "I'm happy and a bit jealous of the German companies and the support that they'll be getting. It's just going a bit slower than France, but it's also the direction. There's increasingly more countries that are taking up the good cause. And it's coming together thanks to the work of other stakeholders in the industry [E]" "We receive subsidies from the French government [G]"
	Regulation	"If there is no infrastructure the waste is sent maybe to someone else who burns it or someone else elsewhere, in another country that disassembles it. We don't know, the information is lost. But why? Because there's no law that obliges. Because the real problem, widely discussed is that we need a law that obliges [A]" "it's not just land use permits that need to be fast tracked and included in the Critical Raw Materials Act legislation. It's a series of other permits as well, including, storage and management and acceptance of naturally occurring radioactive materials because that is the real bottleneck [E]" "the EU is very good in regulating stuff. And if the EU regulates that it's mandatory to recycle the magnets then there will be a waste stream that just flows in [F]"
	Social licence to operate	"In that way (REE carbonate) we are able to ship a non-radioactive product to our separation facility. The reason for that is there's no place in Europe that we can actually get the social licence and the permits to create a graveyard for radioactive wastes [E]"

(continued)

Table A2

2° order themes	1° order themes	Supporting quotes and evidence
Importance of the resource	Geopolitical risk	Case E declares the establishment of a USA–Europe supply chain for radioactive-free REEs carbonate as a real gamechanger for European customer base, as it fills a regulatory gap in Europe and it contributes to meet growing demand in Europe for these materials [press release] "you're losing the stock of materials because you already buy it from China, because the primary sources are all coming from there. And then you lose it again in this way, because if you do not recycle it will go to China (the secondary source) [C]" "the disadvantage compared to Chinese or US manufacturers is 30% (in terms of cost of magnets) [D]" "at the beginning of all, we have a disadvantage of approximately 20, 22, 23% on the raw material (compared to Chinese) [F]"
	Technological competence	"we have also the characterization tools, in order to know the composition and the magnetic performance of the scraps. It makes a big difference, now we are able to recognize it [C]" "The reality is that there isn't much rare earth talent outside of China. The few is in Estonia [E]" "We want to highlight the competences of our experts, and the high technology we put in our process to make sure we are competitive and green. They have a special competency on the separation of rare earth [G]" "it's not uncommon that we have people that have been with us for 20 or 30 years. In the R&D division (we have) trained people. We have several PhDs in their respective fields, but also well trained technical [F]" "We have a great experience and we have a great way to produce the magnets [F]" "we have a complete access to the IP (intellectual property). We have full access to the hydrogen processing of magnet scrap patent [D]" "We have four patents, on this project (magnet separation) [G]"
	Sustainability	"main strength is our process. Definitely. It's I think the most green way to recycle end of life magnet [D]" "ESG informed the selection of the Greenland opportunity (i.e. exploration and mining facility) as energy will come from hydro, a port will be made and everything will be shipped by boat [E]" "(we aim) to have a low environmental footprint. So we had like a series of studies to reduce carbon emissions, recycling also CO2, because we have emission of CO2 during the process, but we use also CO2 during the process. So there is a recycling of CO2 during the process. And regarding water consumption we almost don't have water consumption [G]"
	Price volatility	"It's not just to get the materials, it's also that the prices are not defined. There's not a market (for scraps) and a value that works for us and for them (suppliers) [D]" "when it comes to price volatility control, vertical integration allows us to have (only) one contract with the final consumer, . . . to decouple from Chinese-set price volatility [E]" "the buying behavior needed to be modified a lot, because if the price volatility is not so high, the time of purchase is not critical. But if you have a spike, then there needs to be a lot of checking of prices [F]"
	Supply chain proximity	"There were cost synergies by doing it practically next to our separation facility in Estonia [E]" "Transportation is very expensive. So having like a supplier close to our company it's better because of transportation cost. You know we are buying like waste, two euros per kilogram or less. So it's a very low price in comparison with transport cost [B]" "To assess suppliers, the (important) metric is location basically [B]"
	Cost and complexity of the production process	"there is a critical issue related to the upstream supply chain, which means both the interception and collection of WEEE waste, . . . and its management . . . including the disassembly of the waste, separation, and directing the components towards the best environmental and economic recovery [A]" "(dismantling) is a complexity where however the value is captured on small quantities, because the quantities of the individual components are small quantities [A]" "When you contact manufacturers using permanent magnets what they can give you is big bunch of stuff magnetized and you don't know exactly which is the composition [G]" "the problem is that permanent magnets now are not being recovered and they go with steel parts and end in foundries; (another) problem is that is very difficult to separate permanent magnets from EoL devices [B]"
	Availability of supply material (primary and secondary)	"The upstream supply chain is critical: one of the success factors of the project is certainly linked to the continuity of incoming waste streams for recycling. Currently, the level of control over secondary material streams is low [A]" "having access to raw materials is very difficult and it's very expensive [B]" "There's no continuous flow, they (suppliers) don't know when they're going to have materials [B]" "most critical is to get the scrap. . . . currently we don't know exactly what scrap sources we will get. There are also different qualities of end of life magnets [D]" "(Supplying of secondary materials) is one of the most difficult things in our business model because first there is no market for scrap magnets and you have to look for different suppliers [B]" "there were really times that were extremely challenging with regard to find the material, a lot of uncertainty in the market". [F] "we all know that we don't have enough secondary material so far on the markets [G]"

Source(s): Authors' own work

About the authors

Francesco Ghezzi is a PhD student in Sustainability Management at Sant'Anna School of Advanced Studies. His research interests regard corporate sustainability, sustainable supply chains, natural resource dependence and scarcity and critical raw materials. Francesco has previously worked as a management consultant for the private sector. Now, he is involved in several projects concerning critical raw materials

supply chains in Europe and Africa and sustainable mining in Africa. Francesco Ghezzi is the corresponding author and can be contacted at: francesco.ghezzi@santannapisa.it

Francesco Rizzi is an Associate Professor at the University of Perugia, Department of Economics, with expertise in sustainability management. His work focuses on business strategy, organizational behaviour and innovation management in the green setting. He has published numerous articles in reputable

journals such as *Business Strategy and the Environment*, *Corporate Social Responsibility & Environmental Management*, *Journal of Retailing and Consumer Services*, *Organization*, *Organization & Environment*, *Supply Chain Management*, to cite a few.

Eleonora Annunziata, PhD, is an Associate Professor of Management at the Institute of Management, Sant'Anna School of Advanced Studies, Pisa, Italy. Her research interests focus on corporate sustainability, sustainable entrepreneurship and sustainable supply chain. Her works have been published in journals such as *Business Strategy and the Environment*, *Organization & Environment*, *Corporate Social*

Responsibility & Environmental Management, *Supply Chain Management* and *Energy Policy*.

Marco Frey is a Full Professor of Economics and Business Management and leader of the Interdisciplinary Center SCIC and of the SuM at Sant'Anna School of Advanced Studies, involving +35 researchers, with +50 ongoing research projects on sustainability management. He has published more than 120 articles on major international journals on sustainability topics. Marco Frey is also vice rector of Third Mission and chairman of Global Compact Network Italy Foundation and President of the Scientific Committee of Symbola.

For instructions on how to order reprints of this article, please visit our website:

www.emeraldgroupublishing.com/licensing/reprints.htm

Or contact us for further details: permissions@emeraldinsight.com