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The business perspective on materials criticality: Evidence from manufacturers

Yulia Lapko [a,b,*], Paolo Trucco [a], Cali Nuur [b]

[a] Politecnico di Milano, Department of Management, Economics and Industrial Engineering, Piazza Leonardo da Vinci 32, 20133 Milan, Italy
[b] Department of Industrial Economics and Management, KTH Royal Institute of Technology, Lindstedtsvägen 30, SE-114 28 Stockholm, Sweden

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ABSTRACT

The European Commission identified a group of materials that were claimed to be critical due to their high economic importance and high supply constraints, which could become bottlenecks for the deployment of emerging technologies and enabling sustainable production. Currently this discourse takes place at the industrial system level from a policy perspective, and it is unclear if what is perceived by policy circles as critical could be true for manufacturing operations. This paper explores how five EU manufacturing companies in different sectors and supply chains see materials criticality, and their strategies to mitigate such criticality. On the one hand, the results indicate the limited scope of the criticality factors and employed mitigation strategies considered, compared to those established in the literature. On the other hand, the findings point to the existence of interdependences between companies within and between supply chains, which should be incorporated into the materials criticality assessment, if viable implications for the industrial systems are to be developed. The paper concludes by discussing the implications for manufacturing companies and policy-makers, and suggests prospects for further research.

1. Introduction

Availability of resources has always been a core requirement for the development of nations and economic growth. Historically, the exploration of new areas, population migration and wars have been driven by the need to extend the resource base and ensure its accessibility. Resources have retained their important position, although nowadays the context has changed in various ways. This is a consequence of the exponential increase in the world population and economic growth that drives the consumption of energy and material resources and creates great pressure on their supply (e.g. Krautkraemer, 2005). As Morley and Eatherley (2008) indicate, there are increasing concerns in old industrialised nations about the increasing price of materials and possible shortages of supply inhibiting profitability and volume growth, the increasing control of these resources by fewer organisations, and the allocation of resources in favour of domestic companies via export quotas. Sustainability issues such as sustainable extraction rates, the environmental regulation of mining, and land use competition, add constraints on the availability of materials.

Nonfuel minerals are the resource of particular focus in this study. Generally, there are two views in the literature of the long-term availability of minerals, the fixed stock and the opportunity cost paradigms (Poulton et al., 2013; Tilton, 2003). According to the opportunity cost paradigm, in periods of mineral scarcity, technological progress would be enhanced by the increased price of minerals (Graedel et al., 2014; Gunn and Bloodworth, 2012), however, it is not always possible to include all costs in the price of minerals, as some costs might not be known when price is established, and future changes in the demand and supply base cannot be taken into consideration. As Bell et al. (2013) note, while innovation, discovery, and technological development might be reliable pillars for the mitigation of resource scarcity, there are doubts about whether technology alone is able to solve this. According to the fixed stock paradigm, the depletion of mineral resources is just a matter of time, as the earth is finite and, therefore, mineral supply is also finite (Tilton, 2003).

In recent decades, concerns over the availability of materials have changed from being about the availability of rather basic industrial raw materials such as zinc, lead, and nickel for meeting the demands of the defence industry (known as "strategic" materials), to specialised, low-volume metals (e.g. indium, germanium, rare earth elements) which enable the deployment of green energy technologies in various products (in solar panels, wind turbines, electric vehicles, for example) and modern consumer

* Correspondence to: Politecnico di Milano, via Lambruschini, 4B, Building 26b, 20156 Milan, Italy.
E-mail addresses: yulia.lapko@polimi.it (Y. Lapko), paolo.trucco@polimi.it (P. Trucco), cali.nuur@indek.kth.se (C. Nuur).

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electronics (such as mobile phones, tablets, laptops). From a policy perspective, these are seen as "critical" materials (Buchert et al., 2009; European Commission, 2014a, 2010; Moss et al., 2011; U.S. Department of Energy, 2011).

The concept of materials criticality was born from the concern that some materials (in particular, metals and minerals) may become scarce and no longer routinely available for production and technology (Graedel et al., 2014). In a review of the descriptors of critical raw materials (CRM), Peck et al. (2015) argue that there are no broadly accepted definitions and that the research stream lacks coherence. In general, materials criticality is characterised by a high probability of supply constraints and the high impact of supply destruction (Erdmann and Graedel, 2011; Graedel and Reck, 2015; Peck et al., 2015). Supply constraints can be caused by a myriad of factors such as physical interruptions (e.g. due to war), governmental interventions (e.g. export bans), or market imbalances (e.g. inability to expand supply to meet demand increase, high market concentration) (Erdmann and Graedel, 2011). These supply constraints may lead to two major supply disruptions, a shortage of physical supply, and/or a price increase and volatility, making a material either unavailable or unaffordable (Buijs and Sievers, 2012).

Materials criticality discourse was born at the industrial system level from a policy perspective. Studies of materials criticality analysed materials flows in a scope of a country or region (e.g. European Commission, 2014a; Panousi et al., 2015) or else the analysis was done for a particular set of technologies (e.g. Moss et al., 2011; U.S. Department of Energy, 2011), however, Buijs et al. (2012) suggest that studies disregard the risks related to the production chain and focus instead on the mining and export of raw materials.

From a manufacturing perspective, materials criticality, as a supply-demand mismatch, creates an uncertain business environment and threatens the continuity of production operations. Despite its importance and potential impact on business, to our knowledge, very few studies (Graedel et al., 2012; Mroueh et al., 2014; Rosenau-Tornow et al., 2009; Slowinski et al., 2013) have considered a manufacturer perspective and incorporated implications for businesses when studying materials criticality issues. There is a lack of empirically grounded analysis on the risk factors related to the use of critical materials in the context of manufacturing firms, and on the strategies that manufacturers adopt to mitigate these risks.

The paper aims to address this gap and poses two main research questions:

- RQ1 How do manufacturing companies view and mitigate materials criticality?
- RQ2 How do materials criticality factors and the mitigation strategies employed by companies relate to the factors and strategies established in the literature at the industrial system level?

Supply chain and supplier risks serve as the lenses of analysis in this paper. As the conceptualisation of materials criticality is still developing, these two lenses help in setting the conceptual grounds for an examination of materials criticality at the company level. Supply chain and supplier risk research streams investigate the risks that organisations face through the supply of materials and services, the buyer-supplier relationships, and how they mitigate these risks; we therefore argue that they are useful concepts to identify materials criticality factors from a business perspective. The two lenses of analysis differ in scope and aim to examine whether different companies view materials criticality differently (not only regarding a single factor, but also in the scope of their concern).

The research questions are addressed through exploratory case study research, which is based on a sample of five companies from different industries and from different positions in the supply chain. Building on the literature on supply chain risks, supplier risks and materials criticality, the risk factors related to the use of critical materials and adopted mitigation strategies in the context of manufacturing firms are identified. The findings have implications for the existing materials criticality factors established at the industrial system level, and for policy-makers developing (resources) policy actions in order to establish proper requirements and provide the required support.

After this introduction, the paper is structured as follows. Section 2 provides the theoretical background of materials criticality factors and mitigation strategies from the industrial system level, and supply chain and supplier risk factors and mitigation strategies are reviewed. The section ends with a description of the framework for analysis. Section 3 describes the study methodology. Then, the paper presents (Section 4) and discusses (Section 5) the empirical findings from the five companies. The paper ends with conclusions and implications for business stakeholders and policy-makers, and provides suggestions for further research.

2. Theoretical background

This section is dedicated to materials criticality factors and mitigation strategies as discussed in the literature; and to supply chain and supplier risk factors and mitigation strategies. Finally, the framework of analysis is introduced.

2.1. Materials criticality factors

The analysis of materials criticality has been addressed using various approaches (Erdmann and Graedel, 2011; Graedel and Reck, 2015; Peck et al., 2015). For instance, the European Commission (2010) aggregates materials criticality factors into two dimensions, supply risk and economic importance, but Graedel et al. (2012) analyse materials criticality space with respect to three dimensions, supply risk, the vulnerability of supply restrictions and environmental implications.

Although the dimensions employed in different studies might seem to be alike, they are represented through an aggregation of different factors (Erdmann and Graedel, 2011; Graedel and Reck, 2015). Achzet and Helbig (2013) and Helbig et al. (2016) review factors for measuring supply risk and vulnerability, and both studies suggest a lack of consensus in the literature. Erdmann and Graedel (2011) describe how differently substitutability is addressed in various studies: under supply risks (European Commission, 2010), as a major constituent of vulnerability (NRC, 2008), and as both indicator for vulnerability and supply risk in the assessment methodology of General Electric (Slowinski et al., 2013). Graedel and Reck (2015) suggested that the inclusion of environmental and economic issues in criticality analysis in a generalised framework is rather problematic due to a measurement problem, its relevance to certain materials or to certain levels of analysis.

Materials criticality is a dynamic issue (Graedel et al., 2014) and subject to changes in society's view of certain raw materials, technological change and political vision (Erdmann and Graedel, 2011). The scarcity of other resources required for production processes, such as energy and water, also has an impact on criticality determination (Henckens et al., 2014). The time horizons, organisational levels (e.g. company, industrial system, nation etc.) and particular applications of minerals considered impose limitations on criticality determination (Erdmann and Graedel, 2011; Graedel et al., 2014; Graedel et al., 2012). Table 1 lists the criticality factors found in peer reviewed journal papers, policy reports and