Title: Influence of power regimes on identification and mitigation of material criticality: the case of platinum group metals in the automotive sector

Yulia Lapko. Paolo Trucco

Politecnico di Milano, Department of Management, Economics and Industrial Engineering, Piazza Leonardo da Vinci 32, 20133 Milan, Italy

Lapko, Y. and Trucco, P., 2018. Influence of power regimes on identification and mitigation of material criticality: The case of platinum group metals in the automotive sector. Resources Policy, 59, pp.360-370. https://doi.org/10.1016/j.resourpol.2018.08.008

Highlights:

- Advanced power position enables better identification of supply constrains.
- Advanced power position allows for a wider scope of mitigation actions.
- Power regimes in buyer-supplier relations affect an entire industrial system.
- Power position should be considered in the criticality analysis.

Abstract

The discourse on material criticality assists with the identification of materials that are subject to supply disruptions and have high economic importance within an industrial system. Multiple research efforts generated different lists of critical materials and proposed a variety of mitigation strategies. However, the current discourse substantially misses to consider the business dimension in the criticality analysis. The paper addresses this gap, and in particular, examines power regimes in buyer-supplier relations as mechanisms for shaping company's ability to identify and mitigate material criticality. The empirical investigation is based on the case of platinum group metals employed in the automotive industry. Four companies that form two supply chains were engaged in the study. The findings demonstrate the impact of the power structure on identification and mitigation of material criticality, and highlight examination of the power position as an important part of the criticality analysis process and the consequent mitigation strategy formulation. In an era of globally dispersed supply networks, both practitioners and policy-makers should consider power regimes between companies when developing strategies and policies to secure stable flow of materials.

Key words: critical material, power regime, platinum group metal, automotive industry.

1. Introduction

Geopolitical tensions, environmental restrictions, governmental interventions into resource management pose limitations for accessibility of natural resources in the international arena (Buijs and Sievers, 2012; Graedel et al., 2014). Constrained supply together with the demand from the growing population pose the risk of supply-demand imbalance that may hinder technology development and deployment, and the sustainable development of nations at large. These concerns led to the discourse on material criticality in the policy circles (European Commission, 2010; NRC, 2008).

Materials are considered as critical when they are characterised by high probability of supply disruptions and high economic importance/vulnerability (high impact of supply disruption) (Erdmann and Graedel, 2011; Graedel and Reck, 2015). Recent studies show that many critical materials are employed in technologies ensuring sustainable development such as: indium and gallium in photovoltaic panels, rare earth elements in wind turbines, platinum group metals in catalytic converters (European Commission, 2017a; Moss et al., 2013; U.S. Department of Energy, 2011).

After the introduction of the first criticality analysis by Natural Resource Council in 2008 (NRC, 2008), various assessment methodologies have been developed (e.g., Bach et al., 2017; Graedel et al., 2012) together with a plethora of criticality factors and indicators for their assessment (Achzet and Helbig, 2013; Helbig et al., 2016) in an attempt of grasping and analysing the entire phenomenon. However, the proposed frameworks for the criticality assessment are oriented to examining an industrial system (within a scope of a country or a region) or a particular technology (Helbig et al., 2016; Jin et al., 2016), with only a few studies offering criticality assessment methodology for companies (e.g., Duclos et al., 2010; Graedel et al., 2012).

The existing criticality factors (with their corresponding indicators) characterise aspects affecting availability of a material and dependence (of an industrial system or a company) on a material. Structural/operational conditions the companies operate in, e.g. dependence on a particular provider of a material, are not considered. The suggested frameworks examine companies as independent entities, neglecting the complexity of their interrelations within and across supply chains (and national borders). In relation to the latter, the organisation and management research field particularly indicates that a company cannot be selfsufficient for provision of all resources needed for its operations, and therefore, it engages in resource exchange relations that tie companies into supply chains (Pfeffer and Salancik, 1978; Pfeffer, 1989).

Resource exchange relations have been examined from the power and dependence perspective conceptualised by the resource dependence theory (Pfeffer and Salancik, 1978; Pfeffer, 1989). This perspective on buyer-supplier relations is argued to be indispensable for purchasing and supply management (Cox, 2001a, 1999). In particular, it is indicated that outcomes of an exchange are subject to a power structure (or a regime) between a buyer and a supplier (Cox et al., 2002). Pfeffer (1989)'s argument in favour of a power position as a structural condition for shaping information uncertainty and a range of actions available to a company is supported by various studies (Bode et al., 2011; Maloni and Benton, 2000; Mena et al., 2013). This provides direct implications for ability of a company to identify and address a problem in general and material criticality in particular.

Therefore, the paper aims at examining the role of company relations in identification and mitigation of material criticality by companies, taking the power and dependence perspective. Implications are sought for both criticality analysis at company and industrial system levels, i.e. from business managers and policy makers points of view.

The empirical examination is conducted in the context of platinum group metals (PGMs) (particularly, platinum and palladium) employed in automotive industry. PGMs, as critical materials, are characterised by limited supply sources and constant price fluctuations (European Commission, 2017a). The case is built around three supply chain tiers (catalytic converter production → exhaust systems assembling → car maker) and four manufacturing companies in two supply chains.

This introduction is followed by section 2 that discusses the power-dependence perspective on buyer-supplier relations in the context of material criticality, and builds the research framework. Section 3 describes the employed research methodology. Findings are presented in section 4 and discussed in section 5. The paper ends with conclusions and implications for further research.

2. Power, dependence and materials criticality

2.1. Power and dependence perspective on buyer-supplier relations

The concept of power has been utilised in various research domains (sociology, psychology, marketing, political science, economic context etc.) and examined within different scopes (Belaya et al., 2009; Kähkönen and Virolainen, 2011; Meehan and Wright, 2012), resulting in a plethora of definitions. Emerson defined that "the power of actor A over actor B is the amount of resistance on the part of B which can be potentially overcome by A" (Emerson, 1962, p. 32). According to Emerson's theory of power relations, "power resides implicitly in the other's dependency" (Emerson, 1962, p. 32), implying that A's power over B equals to B's dependence on A. This makes power and dependence are tightly interconnected concepts.

Pfeffer and Salancik (1978) indicated that power consists in control of resources important for a company. They introduced resource dependence theory (RDT) that postulates a) inevitable dependence of companies on their external environment for obtaining resources for their survival (no company can be autonomous); and b) inter-organizational power formation, meaning a company that controls valuable and scarce resources has power over those companies that depend on them (Pfeffer, 1989). These direct resource exchange relations tie companies into supply chains.

Furthermore, Emerson pointed out that "power is a property of the social relation, not an attribute of the actor" (Emerson, 1962, p. 32), highlighting the need to focus on characteristics of the relationship rather than characteristics of individuals engaged in such relations. In line with Emerson, we also adopt so called structural (Cendon and Jarvenpaa, 2001) or organisational (Meehan and Wright, 2012) perspective on power and consider organisational structures (such as resources, interconnection between companies etc.) as attributes/sources of power.

Emerson's conceptualisation of power indicates a necessity for a two-way interaction in a relation. Grounding on this property, Cox with colleagues distinguished four basic power regimes in a buyer-supplier relationship based on a combination of buyer's power over supplier and supplier's power over buyer (Cox, 2015, 2004, 2001b). These regimes are: buyer dominance, supplier dominance, independence and interdependence (figure 1). In addition, Cox et al. (2001) point out that companies operate in a multitude of relations with both upstream and downstream supply chain partners, which should be taken into consideration in the analysis of company's power position. Moreover, Cox et al. (2002) indicate that a power structure at one tier has impact on and is influenced by power structures at other supply chain tiers in terms of value distribution between business partners.

Buyer power attributes relative to supplier	High	Buyer dominance (Supplier dependence)	Interdependence
	Low	Independence	Supplier dominance (Buyer dependence)
		Low	High
		Supplier power attributes relative to buyer	

Figure 1. Power matrix (Cox, 2001b).

The attributes (sources) that comprise power position have been examined by multiple studies (see table 1), which primarily ground on Emerson (1962)'s distinction of two key categories: importance and scarcity of exchanged resources. The attributes reported in table 1 can be summarised into: relative magnitude of the resource exchange to a company's business in terms of revenue and/or market share; regularity and stability of the exchange, availability of equivalent resources from other companies; availability of a resource substitute; ease of switching to another partner and/or a resource substitute; information asymmetry advantage: access to information about an exchange partner and an external environment. While each attribute of power contribute to a power position of a company, it is the joint effect of resource importance and scarcity that lead to the strongest power position (Casciaro and Piskorsk, 2005; Emerson, 1962; Pfeffer and Salancik, 1978). Moreover, keeping in mind the reciprocal nature of power, it is important to understand that 'resource' usually refers to different items for the exchange partners: for example, a material/component for a buyer and profit for a supplier, for example.

Table 1. Attributes of power.

Scarcity of exchanged resources*	Importance of exchanged resources*
• availability/number of alternative partners (Cox et al., 2002; Emerson, 1962; Jacobs, 1974), • availability of alternative sources for resource (Caniëls and Gelderman, 2007, 2005), • switching costs to alternative partner (Caniëls and Gelderman, 2007, 2005; Emerson, 1962), • control over a resource as a level of industry concentration (Crook and Combs, 2007), • isolation mechanisms (property rights, search costs, switching costs etc.) (Cox et al., 2002), • information asymmetry (Cox et al., 2002).	• substitutability and essentiality of a resource (Jacobs, 1974), • financial magnitude (proportion of revenue) (Caniëls and Gelderman, 2007, 2005; Crook and Combs, 2007), • criticality as ability to function without the resource" (Crook and Combs, 2007), as technological expertise of the partner and logistical indispensability (Caniëls and Gelderman, 2007, 2005), • operational importance (number of substitutes of a resource, frequency of transactions) (Cox et al., 2002), • commercial importance (contribution to revenue and cost profile) (Cox et al., 2002).
* 'Resource' usually refers to different items for the exchange partners: a material/component for a buyer and money for a supplier, for example	

In the discourse of organizational dependence the term "criticality" is used in the reference to importance of an exchanged resource. Cox et al. (2002) and Cox (2015) define a resource as critical when it is characterized by both high degree of operational importance and high degree of commercial importance. Grounding on Jacobs (1974)'s division of resource importance dimension into essentiality and substitutability, Caniëls and Gelderman (2007, 2005) and Crook and Combs (2007) refer to criticality of resource as one attribute of essentiality along with financial magnitude. This indicates that a resource does not need to represent a large magnitude of an exchange to be critical. While Crook and Combs (2007) do not operationalize the term "criticality" and refer to it as "ability to function without the resource", Caniëls and Gelderman (2007, 2005) limit it to "technological expertise of a partner" and "logistical indispensability". However, the discourse on material criticality relate the concept to both categories of power attributes (resource importance and scarcity) focusing on continuity of supply in general (see table 2), while 'power' is discussed only as a result of producer concentration (NRC, 2008; Rosenau-Tornow et al., 2009; U.S. Department of Energy, 2011). Table 2 shows that material criticality is examined through a much wider set of influencing factors in comparison to power attributes.

Table 2 shows the similarity between some power attributes and criticality factors. Although there are significant conceptual differences between them. While criticality factors have absolute nature and examine a company's external environment, power attributes have relative nature and examine position of a company against a particular partner (simultaneously considering its position against an examined company). While criticality factors focus on characterising external environment in terms of availability of materials, power attributes focus on a company's ability to access materials. Therefore, power attributes and power position they shape offer a new perspective and, potentially, additional aspects to consider in the criticality analysis.

Table 2. Criticality factors and power attributes.

Criticality factors		Power attributes (PA)					
Company level (Duclos et al., 2010) (Rosenau-Tornow et al., 2009) (Nieto et al., 2013) (Kolotzek et al., 2018) (Graedel et al., 2012)	Industrial system level (Achzet and Helbig, 2013) (Helbig et al., 2016)	PA_1*	PA_2	PA_3	PA_4	PA_5	PA_6
Company concentration	Producer concentration			X**			
Country concentration	Producer concentration			X			
Geological availability	Depletion time Abundance in earth's crust			X			
Co-production risk	By-product dependency			X			
Output of mining/smelting, capacity utilisation	Mine/refinery capacity			X			
Supply trends (future supply market)	Future market capacity Mine production change			X			
Production cost	Production costs in extraction						
Availability of auxiliary resources for production				X			
Investments in supply capacity development (smelters, recyclers etc.)	Exploration degree Investment in mining			X			
Recycling rate/volumes	Recycling/recycling potential			X			
Geopolitical stability	Country governance (risk) Risk of strategic use			X			
Trade restrictions				X			
Import dependence of a company	Import dependence Change in imports			X			
Material price volatility	Volatility of commodity prices Price sensitivity	X					
Demand growth	Demand growth						

	Consumption volume Change in demand share Spread of utilisation Target groups demand share						
Availability of substitutes	Substitutability				X		
Ability to substitute (employ or develop)						X	
Ability to innovate	Ability to innovate (country)					X	
Ability to pass through costs increases		X					
Percentage of revenue impacted	Value of the utilised materials Value of products affected	X					
Importance to corporate strategy	Strategic importance	X					
Environmental and social impact	Environmental and social impact						

** X - similar meaning

* PA_1: Relative magnitude of the resource exchange to a company's business in terms of revenue and/or market share;
PA_2: Regularity and stability of the exchange;
PA_3: Availability of equivalent resources from other companies;
PA_4: Availability of a resource substitute;
PA_5: Ease of switching to another partner and/or a resource substitute;
PA_6: Information asymmetry advantage: access to information about an exchange partner and an external environment.

Information, as an important determinant of power, has direct implications for identification of material criticality. Informational power has been considered in terms of amount of information available for a company and its partners (Cox et al., 2002; Munson et al., 1999), and control over it (Kähkönen and Virolainen, 2011). In relation to the latter, Munson and his colleagues highlight that "companies can gain power by obtaining information, and strong ones can obtain information by using their power"(Munson et al., 1999, p. 59). Therefore, companies with dominant power positions have better visibility about their external environment, while dependent companies face constraints in obtaining information. Given the complexity and multiplicity of material criticality, and plethora of data required for its proper analysis, access to information plays an important role in the identification of material criticality (identification of supply constraints and supply-demand imbalance). Therefore, it is possible to imply that company's ability to identify material criticality can be subject to its power position.

. According to Resource Dependence Theory (RDT), companies attempt to restructure their dependence on external environment in order to secure acquisition of resources and their survival. In particular, Preffer and Salancik (1978) propose two ways to do so: either by obtaining control over a resource (and thus, decreasing dependences) or by increasing dependence of other organisations on themselves. However, the motivation and commitment of a company to act does not always correspond to its ability to act. Casciaro and Piskorsk (2005) warn that a more powerful company will hinder attempts of a dependent company to change its power position. This implies that a dependent position imposes structural constraints on the scope of actions available to a dependent company (Casciaro and Piskorsk, 2005; Cox et al., 2002). Therefore, limitations for actions imposed by a power structure provide implications for company's ability to take actions in order to mitigate material criticality.

2.2. Research framework and questions

Power and dependence aspects of company relations offer a valuable perspective for examination of the role of buyer-supplier relations in material criticality. Extant literature provides implications for the power structures to have impact on company's ability to identify and mitigate material criticality. This paper aims to examine if power relations (conceptualised via power regimes) are important aspects that need to be considered in the criticality analysis. In particular, the following research questions are posed:

- RQ1 How do the power regimes between supply chain tiers affect the identification of material criticality?
- RQ2 How do the power regimes between supply chain tiers affect the mitigation of material criticality?

The research framework is comprised of three key parts: power regimes, identification of critical materials and mitigation of critical materials. They are graphically presented in the figure 2 and described in table 3.

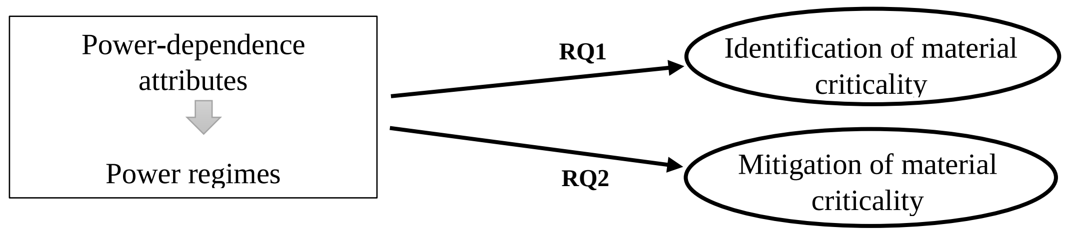

Figure 2. Research framework

Six key power attributes, commonly highlighted in the literature, are employed in this study to examine buyer-supplier relations (Caniëls and Gelderman, 2005; Cool and Henderson, 1998; Cox et al., 2002; Crook and Combs, 2007; Emerson, 1962) (see table 2). Identification of material criticality is considered in terms of experienced supply constraints. Criticality factors listed in table 1 may serve as a reference for possible sources of supply disruptions and their impact. Mitigation of material criticality is considered in terms of actions taken by a company to address supply disruptions. It should be noted that although the connection between identification of constrains and their mitigation is recognised, the process of sensemaking (Grewal et al., 2007; Kiesler and Sproull, 1982) and interpretation (Daft and Weick, 1984) of acquired information is not considered in this study.

Table 3. Dimensions of analysis and descriptions.

Dimensions of analysis	Description
Power attributes	• Relative magnitude of the resource exchange to a company's business in terms of revenue and/or market share • Regularity and stability of the exchange • Availability of equivalent resources from other companies • Availability of a resource substitute • Ease of switching to another partner and/or a resource substitute • Information asymmetry advantage: access to information about an exchange partner and an external environment.
Power regime	• Buyer dominance • Supplier dominance • Independence • Interdependence
Identification of material criticality	Experienced concerns about continuity of supply and supply-demand imbalance
Mitigation of material criticality	Actions taken to ensure continuity of supply

3. Methodology

The exploratory case study is chosen as a research approach for this study. This choice is driven by the complexity of material criticality phenomenon, lack of agreement among researchers on what makes materials critical and how to efficiently address those issues. This approach is argued to be beneficial for gaining understanding of a multidimensional phenomenon (Barratt et al., 2011; Eisenhardt and Graebner, 2007; Yin, 2009). A few available empirical studies also employed case based research design, engaging with companies from different industries (Lapko et al., 2016; Mroueh et al., 2014; Slowinski et al., 2013).

Given the aim of examining the influence of power regimes on how companies identify and mitigate material criticality, the unit of analysis in this study is a supply chain and the level of analysis is a company.

3.1. Selection of companies

The choices of PGMs (palladium and platinum) among critical materials and automotive catalytic converters among PGMs' applications are justified by the suitability for the study. Criticality of PGMs is mainly driven by high prices and constant price volatility, high concentration of supply in producing countries (more than 70% of palladium and platinum is produced in South Africa and Russia) and low substitutability (European Commission, 2017b). PGMs have had relatively constant nature of supply constraints over the last decade. In the EU, about 80% of PGMs are employed in autocatalysts (European Commission, 2017b), what makes it the key application. In addition, it is a rather "old" established technology, what allows examining buyer-supplier relations in the industry and supply chain with formed traditions and standards, and thus, avoiding rather transient period of supply chain formation for many critical materials (CRMs) employed in emerging technologies, such as electric mobility for example.

The literature on organisational power and dependence tends to investigate and/or provide implications only for one side of buyer-supplier relations regardless complex reciprocal nature of power relations (Bode et al., 2011; Casciaro and Piskorsk, 2005; Heide and John, 1988). In contrast, this study engages with both exchange partners in each dyad along a supply chain and in addition takes into consideration the implications for interrelations between power regimes at different tiers in a supply chain (Cox et al., 2002). Three tiers in the supply chain of PGMs in automotive industry are taken into consideration: catalytic converter (tier-2) →

exhaust system (tier-1) → carmaker (original equipment manufacturer, or OEM). Two supply chains are considered: with niche and large automotive manufacturers that share tier-2 and tier-1 suppliers (see figure 3). The choice of different OEMs serves for ensuring diverse empirical contexts. In total four companies were engaged, all located in the EU. Geographical scope is important as material criticality issues are subject to demand and supply dynamics of a particular region (European Commission, 2017a; Graedel et al., 2012). For example, employment of automotive catalytic converters is strongly dependent on emission-control legislation, which varies in different countries.

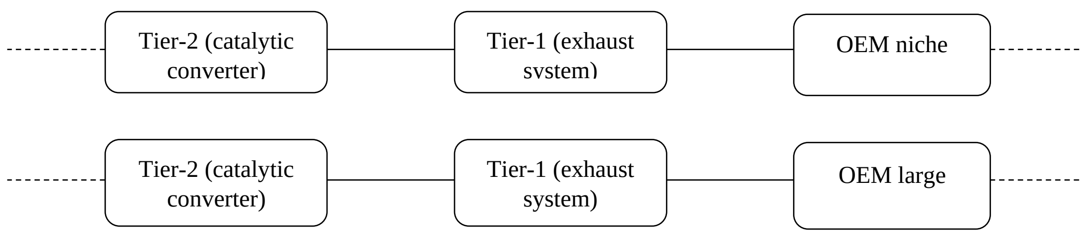

Figure 3. Structural representation of the selected companies.

3.2. Data collection

Data collection was performed via semi-structured interviews and via review of annual and sustainability reports from last three years to ensure relevance of the collected data to the current relations with supply chain partners. Engagement of both primary and secondary data allowed for data triangulation and reduction of possible interviewee's bias (Eisenhardt, 1989). However, data for tier-1 supplier were collected only from various secondary sources, which were triangulated against comments of OEMs and tier-2 supplier. More detailed examination of tier-1 supplier was not critical, as the company is not engaged into management of PGMs, and OEMs have direct relationship with tier-2 supplier. When a company provided implications about its partners, we had an opportunity to control such statements on consistency and triangulate them with data obtained from their partners.

Interviewees were selected based on their responsibility/expertise in PGMs purchasing and supply management (see table 4). Each interview lasted between 60 and 90 mins; all were conducted via phone or in person during spring 2017. With the permission of the interviewees, the interviews were recorded and transcribed for further analysis.

The dimensions of the research framework served as a basis for the interview protocol development and search for information in companies' reports. In particular, the following key topics were distinguished:

- experienced PGMs supply constraints (as indication for identification of material criticality);
- actions taken to secure PGMs supply (as indication for mitigation of material criticality);
- PGMs supply and purchasing structure, possibility to substitute PGMs and/or suppliers, information available about an exchange partner and an external environment (as implications for power attributes); in order to avoid possible bias, the companies were not aware about the list of power attributes and the discussion was guided by the interviewer to clarify all aspects of power structures).

Table 4. Profile of the companies interviewed.

Company	Revenue (billion €)	Number of employees (thousands)	Interviewer position (function)	Date of interview	Secondary data
Tier 2	10-15	10-15	Technical Manager(link between R&D and business strategy)	April 2017	Annual reports 2013/14; 2014/15; 2015/16; 2016/17.
Tier 1	15-20	95-100	n.a.	n.a.	Annual reports 2014; 2015; 2016.
Niche OEM	25-30	35-40	Supply chain projects manager	March 2017	Annual reports 2013/14; 2014/15; 2015/16; 2016/17 Sustainability reports 2013/14; 2014/15; 2015/16.
Large OEM	90-95	140-145	Operations Manager in New Product/Model Development department	May 2017	Annual and Sustainability reports 2015; 2016; 2017.

3.3. Data analysis

Data analysis started with the coding of the collected primary and secondary data based on dimensions of analysis from table 3. All examined companies report PGMs related issues and their management under financial and/or commodity price risks, what facilitated the coding process for identification and mitigation of material criticality. For example, large OEM states that "for precious metals, used in catalysts, to minimise commodity price volatility exposure the company makes continuous efforts to reduce usage through technological innovation; uses fixed-rate purchase contracts …". The most attention had to be dedicated to implications for the power attributes. For example, tier-1 indicates that the production of the exhaust system comprises around 30% of total production. This statement is relevant for several power attributes: 'relative magnitude of resource exchange' indicating that the rest of company's profits depends on other products in its portfolio; 'availability of resource substitute' indicating that the company may obtain profit also from other business segments (please, consider that for a supplier a resource in an exchange is revenue). Niche OEM describes its supply structure in the following way "for smaller companies as us, it is a single source supply per component only, and the reason for that is investment required to bring a supplier on board". This statement was considered as implication for 'availability of equivalent sources' and 'ease of switching to another partner'. The following comments of tier-2 company were considered as contribution to 'information asymmetry advantage' attribute of power: "deep understanding of markets and customers enables the division to provide the right solutions for its customers in evolving markets driven by tightening legislation" or "with our deep understanding of the distribution of platinum, palladium, rhodium in our catalysts, we are able to minimise the amounts of precious metal required to do the job"

Once the coding process was completed, the data was analysed in the following manner:

- each company was examined on concerns regarding supply and demand conditions (criticality factors) associated with PGMs, actions taken for PGMs management and relevant power attributes;
- each dyad was examined on the power regime;
- power positions of companies were examined against their ability to identify and mitigate material criticality.

3.4. Rigor of the study

Rigor of the study was assessed based on five trustworthiness criteria adopted from interpretive research approach (Guba, 1981; Hirschman, 1986; Wallendorf and Belk, 1989). This approach is often employed for qualitative inductive research (Gaudenzi et al., 2017; Manuj and Mentzer, 2008). Table 5 shows that the methodology employed met these criteria.

Table 5. Rigor of the study.

Criteria and explanation	Steps to address the criteria
Credibility (extent to which the results appear to be acceptable (adequate and believable) representations of the reality)	• No contradictory evidence was identified via triangulation of primary and secondary data sources for each company, as well as via triangulation of implications of companies about each other. • Understanding of obtained information from both interviews and reports were verified with the interviewees during and after the interviews.
Transferability (extent to which the findings from a study in one context will apply to other contexts)	• Selected companies represent two supply chains with different kinds of relationships, with niche and large OEM. • PGMs supply constraints are common also for other critical materials.
Dependability (extent to which the findings are subject to time and place, or could be repeated under similar examination)	• All interviewees are knowledgeable about the use of PGMs, characteristics of PGMs supply and purchasing structure related risks, employed mitigation actions, , nature of relations with supply chain partners. • Protocols for data collection and analysis.
Confirmability (extent to which the findings are not subject to biases of different nature)	• Triangulation of data sources: interviews, annual and sustainability reports. • Understanding of obtained information from both interviews and reports were verified with the interviewees during and after the interviews.
Integrity (extent to which interpretations are influenced by misinformation or evasions by participants)	• Confidentiality assurance to participants. • No contradictory evidence was identified via triangulation of primary and secondary data sources for each company, as well as via triangulation of implications of companies about each other.

4. Findings

4.1. Power regimes between supply chain tiers

The obtained evidence provides implications for the power regimes between supply chain tiers in relation to exchange of PGMs (embedded in components). Power attributes are reported in tables 6 and 7, and power regimes are graphically represented in figure 4 below.

Tier-1 and tier-2 are rather independent in relation to PGMs (reported in figure 4 as: tier 1 0 tier 2). The niche and large OEMs define suppliers of catalytic converters and order their delivery to tier-1 for further assembly of exhaust systems. Tier-1 supplier is not affected by price volatility of PGMs, it is passed through on an OEM (niche or large). Although power attributes in dyads OEM–tier-1 and OEM–tier-2 appear to have a similar pattern, the power regimes in dyads are different.

Both catalytic converters and exhaust systems are designed specifically to fit an architecture of a certain car model. This makes it difficult for each party to switch to another exchange partner during the production of that car model. However, OEM has a more powerful position in relation to its suppliers due to uncertain demand that is subject to multiple factors and is not guaranteed in contractual agreements. This uncertainty and link to OEM with a tailor made product tie a tier-1 supplier to a buyer, raising the dominance of the latter. The bigger is the magnitude of the exchange the higher is the buyer dominance, which puts large OEM in more dominant position against tier-1 supplier (tier-1 << OEM large), comparing to niche OEM (tier-1 < OEM niche).

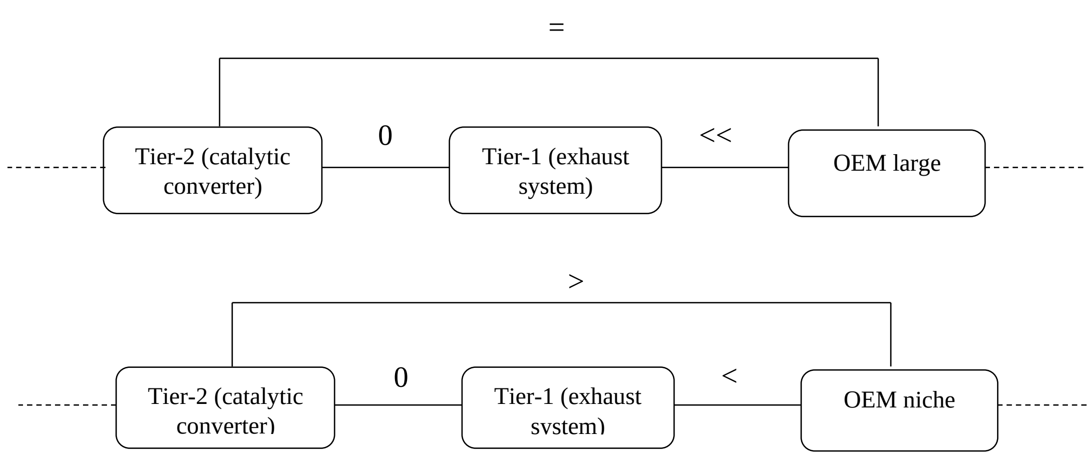

Figure 4. Distribution of power in the supply chain of niche and large OEMs.

Comparing to tier-1, tier-2 supplier has more powerful position in dyads with OEMs. Tier-2 company obtains access to PGMs, have knowledge of PGMs market and a technological expertise to produce a component that allows OEMs to meet legislative requirements regarding air emissions. Tier-2 has an advantage of industrial practice to pass PGMs price fluctuation on downstream partners. In particular, the price of catalytic converters consists of manufacturing costs (controlled by tier-2) and PGMs price (not controlled by tier-2). This advantage is particularly evident in comparison to rare earth elements, which are also present in automotive catalytic converters. In 2010-11 there was a sharp increase in their prices and tier-2 supplier had to renegotiate price conditions with OEMs.

The comparison of carmaker indicates that large OEM gains more power than niche OEM in relation to tier-2 thanks to magnitude of the exchange, the concurrent sourcing from several suppliers of catalytic converters and understanding of PGMs market structure. It is possible to imply that they are interdependent and have relatively equal power positions in relation to each other (tier-2 = OEM large). Niche OEM also counts on magnitude of the exchange as an important source of power and does so by purchasing all catalytic converters from a single supplier. However, dependence on a single supplier and marginal volumes (comparing to other customers of tier-2) limit niche OEM's power and put tier-2 supplier in a dominant position (tier-2 > OEM niche).

The case of PGMs provides an example of power distribution in a supply chain and more specifically demonstrates a power dominance of upstream suppliers. Importance and uncertainty of PGMs brings OEM's attention to the earlier tiers of the supply chain, if not to its origin. As a result, OEM directly operates with tier-2 supplier in order to have better control over components that contain PGMs.

Table 6. Attributes of power in dyads of OEM and tier-1.

Attributes	Tier-1	OEM large	OEM niche
Relative magnitude of the resource exchange	- A diversified portfolio of products, where exhaust systems have a major proportion (~30%) - Niche OEM comprises a marginal proportion of total sales - Large OEM comprises a significant proportion of total sales (~15%)	- Costs of raw materials and consumables comprises ~60% of revenues.	- Costs of raw materials and consumables comprises ~50% of total sales

Regularity and stability of the exchange	- Volumes and period of a contract with OEM that are uncertain and subject to the success of a car model, OEM and automotive industry, environmental legislation.	- The exchange relations are regulated by the contract, and are ultimately subject to the success of a car model, OEM and automotive industry, environmental legislation.	
Availability of equivalent resources from other companies (exhaust system – for buyers; revenue – for suppliers)	- A diversified portfolio of customers for exhaust systems	- Many suppliers of exhaust systems are available at the market. - An exhaust system for a specific car model is usually supplied from a single supplier. - Exhaust systems for different car models are purchased from different suppliers.	
		- In a case of very big volumes of production, the exhaust system for the same car model can be purchased from more than one supplier.	
Availability of a resource substitute	- A diversified portfolio of products, where exhaust systems. have a major proportion (~30%) - A diversified portfolio of customers for exhaust systems.	- Substitution of exhaust systems is possible in new car models (electric vehicles), but they comprise marginal proportion of product portfolio and total sales	
Ease of switching to another partner or a resource substitute	- The product is designed to fit architecture of a specific car model. The contract is awarded based on competitive bids (OEM request for quotation). - High competition in automotive industry: many component manufacturers.	- Switching a supplier is problematic, as a component is designed to fit architecture of a specific car model.	
		- Big volumes of production make it more difficult to find another supplier.	- Small volumes of production make it easier to find another supplier (e.g. as a temporary solution).
Information asymmetry advantage	- Volumes and period of a contract with OEM that are uncertain and subject to the success of a car model, OEM and automotive industry, environmental legislation. - Have to adapt its business activity to its customers' demands in terms of supply chain, production operations, services and R&D.	- OEM determines characteristics of components and choose a supplier based on tender. OEM is aware about supplier's production process and costs structure. The exchange is subject to the contract conditions. - Knowledge about automotive market structure and demand trends. - Audit of suppliers - Requirement for suppliers to meet the company's purchasing guidelines	

Table 7. Attributes of power in dyads of OEM and tier-2.

<table>
<tr><th>Attributes</th><th>Tier-2</th><th>OEM large</th><th>OEM niche</th></tr>
<tr><td>Relative magnitude of the resource exchange</td><td>- A diversified portfolio of products, where exhaust systems have a major proportion (~60%).
- Niche OEM comprises a marginal proportion of total sales.
- Large OEM comprises a significant proportion of total sales.</td><td>- Costs of raw materials and consumables comprises ~60% of revenues.</td><td>- Costs of raw materials and consumables comprises ~50% of total sales</td></tr>
<tr><td>Regularity and stability of the exchange</td><td>- Volumes and period of a contract with OEM that are uncertain and subject to the success of a car model, OEM and automotive industry, environmental legislation.</td><td colspan="2">- The exchange relations are regulated by the contract, and are ultimately subject to the success of a car model, OEM and automotive industry, environmental legislation.</td></tr>
<tr><td rowspan="2">Availability of equivalent resources from other companies (catalytic converters – for buyers; revenue – for suppliers)</td><td rowspan="2">- A diversified portfolio of customers of catalytic converters</td><td colspan="2">- Many suppliers of catalytic converters are available at the market.
- Catalytic converters for a specific car model are usually supplied from a single supplier.</td></tr>
<tr><td>- Catalytic converters for different car models are purchased from different suppliers.
- In a case of very high volumes of production, the same catalytic converters can be purchased from several suppliers</td><td>- Catalytic converters for all car models are purchased from a single supplier</td></tr>
<tr><td>Availability of a resource substitute</td><td>- A diversified portfolio of products, where exhaust systems have a major proportion (~60%).
- A diversified portfolio of customers of catalytic converters.
-Investments in development of next generation technologies (batteries, fuel cells)</td><td colspan="2">- Substitution of catalytic converters is possible by shifting to electric vehicles, but they comprise marginal proportion of product portfolio and total sales.
- PGM are indispensable elements of catalytic converters</td></tr>
<tr><td rowspan="2">Ease of switching to another partner or a resource substitute</td><td rowspan="2">- The product is designed to fit architecture of a specific car model.
The contract is awarded based on competitive bids (OEM request for quotation).
- High competition in automotive industry: many other component manufacturers.</td><td colspan="2">- Switching a supplier is problematic, as a component is designed to fit architecture of a specific car model.</td></tr>
<tr><td>- Big volumes of production make it more difficult to find another supplier.</td><td>- Catalytic converters for all car models are purchased from a single supplier</td></tr>
</table>

<table>
<tr><td></td><td></td><td></td><td>- Small volumes of production make it easier to find another supplier (e.g. as a temporary solution).</td></tr>
<tr><td rowspan="2">Information asymmetry advantage</td><td rowspan="2">- Volumes and period of a contract with OEM that are uncertain and subject to the success of a car model, OEM and automotive industry, environmental legislation.
- Understanding of the product market structure, customer’s needs, demand, trends, legislation.
- Expertise in PGM chemistry, materials science and manufacturing
- Expertise of emissions control technologies that allows OEM to meet world/EU emission standards.
- Expertise in PGM management and distribution: market structure, mining/production capacity
- Expertise in PGM refining and recycling technology</td><td colspan="2">- OEM determines characteristics of components and choose a supplier based on tender. OEM is aware about supplier’s production process and costs structure. The exchange is subject to the contract conditions.
- Understanding automotive market structure and demand trends.
-Awareness about PGM price volatility and PGM market structure
- Audit of suppliers
- Requirement for suppliers to meet the company’s purchasing guidelines</td></tr>
<tr><td>- Disclosure of information on financial situation, results and business activities
- Supply chain database including suppliers, their components and their materials</td><td></td></tr>
</table>

4.2. Identification and mitigation of material criticality

As tier-1 supplier is not directly involved in PGMs management and/or affected by supply constraints of PGMs, tier-2 supplier and OEMs (large and niche) are considered regarding identification and mitigation of material criticality. Table 8 presents expressed concerns over continuity of PGMs supply (identification) and actions taken to mitigate supply constraints (mitigation)

All examined companies highlight PGMs price volatility and price competition at the product market as a problem. While niche OEM has concerns mainly about PGMs affordability (price fluctuations), large OEM and tier-2 indicate constraints regarding both PGMs price and volumes. Tier-2 also mentions geopolitical constraints and has better understanding of PGMs market. In addition, it should be noted that niche OEM’s smaller purchased volumes create an illusion of lower exposure to the supply constraints of PGMs.

Both OEMs have to accept PGMs price fluctuation, as it is a practice in the automotive industry. Niche OEM addresses the situation with monitoring PGMs pricing and contractual mechanism (conditions for escalation clauses and short-term fixed prices). While niche OEM has only one tier-2 supplier for all car models, large OEM sources catalytic converters from several tier-2 suppliers for different car models. In addition, large OEM puts efforts in research to minimise PGMs needs. Tier-2 supplier has the broadest scope of actions that also includes PGMs refinery and recycling as additional sources of PGMs supply.

Table 8. Identification and mitigation of material criticality.

	Tier-2	OEM large	OEM niche
Identi-fication	• Price fluctuation of PGMs. • Limited number of PGMs supply sources. • Stability of a producing county. • Price competition at a product market.	• Price fluctuation of PGMs. • Limited number of PGMs supply sources. • Price competition at a product market.	• Price fluctuation of PGMs. • Price competition at a product market.
Mitiga-tion	• Sourcing from three different geographical locations. • Audit of suppliers. • Manufacturing units are located nearby PGMs mining cites. • Monitor supply conditions (price, availability, delays etc.). • Pass the price fluctuation to OEM. • Inventories of PGMs. • Financial hedging. • Product innovation to minimize use of PGMs. • Recycling of PGMs.	• Accept price fluctuation. • Short-term fixed price contracts. • Financial hedging. • Purchase from more than one supplier in case of large production volumes. • Tier-2 suppliers for different car models are different. • Research on substitution and/or minimization of PGMs use. • Monitor PGMs prices.	• Accept price fluctuation. (Only one tier-2 supplier for all models). • Monitor PGMs prices. • Long-term partnerships with the supplier. • Derivative and fixed price contracts with suppliers.

5. Discussion

This section starts with a general discussion of the findings aimed at answering the initially posed research questions. Then, the implications for the criticality analysis at the company and industrial system levels are provided.

5.1. Influence of power regimes on identification and mitigation of material criticality

The findings demonstrate influence of power structure on identification and mitigation of material criticality by companies. In line with prior literature (Cox et al., 2002; Munson et al., 1999), we found that a more advanced power position is associated with better visibility of the external environment and facility in obtaining information about it. This leads to better awareness of supply and demand conditions, and thus, better identification of material criticality. The opposite is true for the dependent position. This is evident when comparing tier-2 supplier with OEMs, and niche with large OEMs (see table 8). Although the criticality discourse acknowledges that companies often lack visibility over supply chains and industrial systems at large (e.g. Nieto et al., 2013; Slowinski et al., 2013), the current criticality assessment frameworks do not take into consideration the impact of information completeness. Lack of transparency and information asymmetry lead to higher material criticality for a dependent company.

In relation to the mitigation, the results shows that more advanced power position allows for a bigger scope of feasible actions to choose from. This finding supports the literature that indicates power structure as a constraint for a possibility to take actions (Casciaro and Piskorsk, 2005; Cox et al., 2002). While tier-2 supplier and large OEM employ various actions to address supply constraints in relation to PGMs affordability (price) and availability (volume), niche OEM has a smaller scope of feasible options at hand in its rather dependent position (see table 8). However, dominant power position in a relationship does not necessarily mean no need for mitigating material criticality. For example, neither the advantage in PGMs price formation nor rather dominant position in relation to OEMs mitigate material criticality for tier-2 supplier. The company still has to secure its business stability via ensuring access to PGMs and their timely delivery.

Moreover, the findings allow implying that the scope of actions of a dependent company is influenced by actions taken by other (more powerful, dominant) supply chain actors. For example, OEMs directly source PGMs from tier-2 supplier, what leaves tier-1 supplier out of PGMs management. On the one hand, such an OEMs' strategy seems to shield tier-1 supplier from PGMs supply issues and overall concerns over criticality (note that the application of current criticality analysis frameworks to tier-1 supplier would lead to the same conclusion). On the other hand, it creates strong dependence of tier-1 supplier's business on the efficiency of mitigation actions put in place by OEMs. Indeed, if OEM fails to secure access to PGMs, the established contractual agreements between tier-1 and OEM will not be accomplished. This reveals that PGMs are still critical for tier-1, regardless what current criticality analysis at the company level would imply. Moreover, this criticality is caused by the company's dependence on its customer rather than its supplier, which would be a more typical case. This dependence of tier-1 supplier on a powerful customer is higher in the supply chain with large OEM due to the higher magnitude of exchange. It is important to note that the current criticality analysis is not capable of grasping these dynamics.

The results highlight that criticality mitigation actions employed by companies are driven to restructure their power position and minimize dependence on exchange partners and on PGMs. This is done by acquiring power attributes, such as reduction of exchange magnitude with a particular partner via sourcing from multiple suppliers; additional supply sources via recycling; acquisition of information to reduce information asymmetry via monitoring and audit. Information appears to be an important source of power that can assist to gain visibility (and thus, better identification of material criticality) and also to restructure power position (and thus, widen the scope of mitigation actions) (c.f. Munson et al., 1999).

Overall, the findings indicate that the power position analysis has an important role in examining material criticality. Companies in a dependent position are characterised by constrained access to information and limited toolbox of feasible actions, both of which lead to higher material criticality for them (and therefore, for an industrial system where such companies operate). The current assessment methodologies might generate misleading results if they neglect how companies relate to each other (within a supply chain and an industrial sector) and how these relations influence their ability to identify and mitigate material criticality. It is not sufficient to examine only characteristics of a material flow and its throughput values at different supply chain tiers, or identify key supply chain actors according to the current practice (e.g. European Commission, 2017a; U.S. Department of Energy, 2010).

5.2. Implications for criticality analysis at the company level

Companies are engaged in multiple relations and, according to our findings, these relations influence their ability to identify and mitigate material criticality, and therefore, they cannot be ignored. In particular, this study highlights the need to examine the power positions of companies as part of the criticality analysis process.

As it was discussed in Section 2, some power attributes may appear similar to criticality factors (e.g., ability to substitute), while others characterise aspects that have not been addressed in the criticality analysis (e.g., ease of switching to another partner and information asymmetry). However, it does not necessarily imply that the "missing" power attributes should be added to the current criticality assessment methodologies. Power attributes are meaningful only when considered holistically and when examined in relation to a resource exchange partner (Casciaro and Piskorsk, 2005; Emerson, 1962; Pfeffer and Salancik, 1978). That is why it is important to analyse the power position itself, not just some of its attributes. Given that a company is involved in buyer-supplier relations with different power regimes, it is necessary to consider its power position in all relations relevant for the management of a potentially critical material.

Despite Dewulf et al. (2016) argues against the inclusion of mitigation-related factors in the criticality analysis, the current approach is in favour of consideration of feasibility of mitigation efforts. In particular, existing methodologies take account for three related such factors: 'ability to substitute', 'ability to innovate' and 'ability to pass-through costs increases' (see table 2). The reasoning behind such selection is not always well justified, and it is not clear why other aspects are excluded, such the ability to switch to another supplier/customer or the benefits/constraints coming from actions taken by other supply chain actors with stronger power positions. We argue that constrained company's ability to take mitigation actions leads to higher material criticality. Availability of a material at the resource market or presence of several suppliers does not imply that all companies would be able to gain access to that material, that they supply it from multiple sources or that it would be easy for them to switch to another supplier potentially present at the market. Specificities of business models, contractual agreements and product specifications impose at least temporal restrictions in addition to actual capabilities of companies.

We propose to perform examination of power position and power distribution in a supply chain as a complementary part in the criticality analysis process. Given the similarity between some power attributes and criticality factors, it is important to ensure that there is no "double counting" of the same aspects. In general, taking into consideration the results of the present study, we are more in favour of considering the power position analysis as a key for correctly interpreting criticality factors, and selecting coherent and actionable mitigation actions. For example, the availability of substitute at the market is no guarantee that a company is able to employ it. It could be due to technical capabilities or due to constraints imposed by a customer. Furthermore, limited ability to substitute does not imply higher criticality for all companies. If we look at our empirical data, OEM's inability to substitute PGMs increases the criticality state for that company, but this is not true if we consider the tier-1 supplier. The same applies to 'percentage of revenue impacted': tier-1 supplier can be even more exposed than OEM to this factor, but it explains nothing of the level of criticality of PGMs for tier-1 supplier. These ambiguities can be solved only by considering different power positions of these actors. Moreover, if we look at 'ability to pass through cost increase', it represents a feasible mitigation action enabled by a specific power regime, rather than a power attribute per se. It is possible to imply that full awareness of own power position allows a company to better interpreting if and how specific criticality factors contribute to criticality. The issue is even more relevant when considering mitigation actions. Our results clarify that it is not possible to get any real guidance, on how to select actionable and effective countermeasure, from criticality factors per se, without a real understanding of the company's power position.

However, proposing a revision of criticality assessment frameworks is beyond the scope of this study and requires further investigation.

5.3. Implications for criticality analysis at the industrial system level

Examination of the power structure is also relevant for the criticality analysis at the industrial system level. The power positions of companies (and associated ability to identify and mitigate material criticality) shapes a position of an industrial system they comprise against other industrial systems. If within the scope of a country there are companies with dominant positions in their respective supply chains, they will ultimately foster a more powerful position of that country in the international arena in relation to resource management. Buijs and Sievers (2012) argue that control of resource production and/or exports grants political or economic power and there must be a shift of power from resource consumer to resource producer countries. However, the conducted analysis of the power structure in the supply chain highlights that the power relations are more complex and the "shift" is not necessarily linear, meaning that operating upstream in supply chains does not grant power by default.

Examination of power structure within an industrial system allows for differentiated identification of material criticality in order to reflect specificities of a material's applications and companies within that system. This study demonstrates that, within the same industry, different actors may have significantly different concerns over the same critical material (and they may adopt radically different mitigation strategies). The differences are associated with specific power positions, which cannot be captured properly just by looking at the function (e.g. smelter, manufacturer) or even the position of the company in the supply chain (e.g., tier-1 vs tier-2 suppliers). Examination of power structure within the criticality analysis process would allow taking into consideration such differences and providing results that are more meaningful. General lists of critical materials might not appear relevant for all companies, be it due to differences in results of the criticality assessments conducted in different countries (but still within the scope of a company's operations) or due to differences among companies in terms of their ability to identify risks and act upon them.

The current criticality analysis at the industrial system level ends at producing a list of materials labelled as critical. The criticality mitigation is addressed by considering "recyclability" and "substitutability" as criticality factors. However, they do not actually reflect the ability (and interest) of companies comprising a certain industrial system to recycle material, to employ recycled material, to develop and employ substitutes. Mitigation strategies are usually discussed separately and provided as a general list of recommended actions without feasibility check. Examination of power structure as a part of the criticality analysis process allows better understanding of (differentiated) constraints companies face, and therefore, provides better ground for shaping resource policy. Moreover, building on the obtained findings, it is possible to imply that the scope of feasible actions within an industrial system depends on limitations of each company (imposed by power position), but also on strategies deployed in other industrial systems with dominant powerful position (an industrial system comprised by companies with dominant power positions).

Examination of the power structure as a part of the criticality analysis at the industrial system level helps in grasping additional aspects influencing material criticality that has been overlooked before, and taking into consideration heterogeneity of companies in terms of their ability to identify and mitigate material criticality. Finally, it better positions the criticality analysis as a useful instrument for supporting decision-making regarding resource management.

6. Conclusions

This study contributes to the material criticality discourse by highlighting the importance of taking into consideration the company dynamics in the assessment frameworks and providing implications for the influence of power position and power structure on identification and mitigation of material criticality at both company and industrial system levels. Advanced power position of a company is associated with better visibility over supply constraints and supply-demand imbalance, and a wider scope of feasible mitigation actions. Considering the opposite is true, information uncertainty and constrained ability to take actions increase criticality state for companies in dependent positions. The power positions of companies form the power position of an industrial system they comprise with associated limitations and possible dependence on other industrial systems. While examination of the power structure at the company level helps to take into consideration additional influencing forces (not considered yet), at the industrial system level it allows providing more refined outcomes, reflecting heterogeneity of companies and considering possible dependence on other industrial systems. At the either levels, analysis of the power position supports decision-making proving better account of feasibility and constrains of mitigation options. This study proposes to consider examination of power structure as a complementary analysis within the criticality analysis process, to be carried out before the examination of each single criticality factor.

Further research opportunities can be formulated as following. The obtained empirical evidence demonstrates that companies operate in complex networks, therefore, it is important to examine power structures within the network of suppliers in order to properly understand how companies view and respond to material criticality. It is necessary to enlarge the study by involving more tiers in the supply chain preferably including mining companies, as it will enable to consider all stages of transformation of a material. Examination of power structures was limited to a certain dyad/supply chain and a product market/industry in this study. However, a critical material is employed in multiple applications, and this requires considering power position of a company not only in relation to its direct exchange partners in the industry, but also against other industries, where the same material is employed. Further studies with a methodological focus should also aim at proposing and validating how to incorporate the power position analysis into current criticality assessment frameworks.

References

Achzet, B., Helbig, C., 2013. How to evaluate raw material supply risks—an overview. Resour. Policy 38, 435–447. doi:10.1016/j.resourpol.2013.06.003

Bach, V., Finogenova, N., Berger, M., Winter, L., Finkbeiner, M., 2017. Enhancing the assessment of critical resource use at the country level with the SCARCE method – Case study of Germany. Resour. Policy 53, 283–299. doi:10.1016/j.resourpol.2017.07.003

Barratt, M., Choi, T.Y., Li, M., 2011. Qualitative case studies in operations management: Trends, research outcomes, and future research implications. J. Oper. Manag. 29, 329–342. doi:10.1016/j.jom.2010.06.002

Belaya, V., Gagalyuk, T., Hanf, J., 2009. Measuring asymmetrical power distribution in supply chain networks: What is the appropriate method? J. Relatsh. Mark. 8, 165–193. doi:10.1080/15332660902876927

Bode, C., Wagner, S.M., Petersen, K.J., Ellram, L.M., 2011. Understanding responses to supply chain disruptions: Insights from information processing and resource dependence perspectives. Acad. Manag. J. 54, 833–856. doi:10.5465/AMJ.2011.64870145

Buijs, B., Sievers, H., 2012. Critical Thinking about Critical Minerals : Assessing risks related to resource security.

Caniëls, M.C.J., Gelderman, C.J., 2007. Power and interdependence in buyer supplier relationships: A purchasing portfolio approach. Ind. Mark. Manag. 36, 219–229. doi:10.1016/j.indmarman.2005.08.012

Caniëls, M.C.J., Gelderman, C.J., 2005. Purchasing strategies in the Kraljic matrix—A power and dependence perspective. J. Purch. Supply Manag. 11, 141–155. doi:10.1016/j.pursup.2005.10.004

Casciaro, T., Piskorsk, M.J., 2005. Power Imbalance , Mutual Dependence , and Constraint Absorption : A Closer Look at Resource Dependence Theory. Adm. Sci. Q. 50, 167–199.

Cendon, B.V., Jarvenpaa, S.L., 2001. The development and exercise of power by leaders of support units in implementing information technology-based services. J. Strateg. Inf. Syst. 10, 121–158.

Cool, K., Henderson, J., 1998. Power and Firm Profitability in Supply Chains : French Manufacturing Industry in 1993. Strateg. Manag. J. 19, 909–926.

Cox, A., 2015. Sourcing portfolio analysis and power positioning: towards a “paradigm shift” in category management and strategic sourcing. Supply Chain Manag. An Int. J. 20, 717–736. doi:10.1108/SCM-06-2015-0226

Cox, A., 2004. The art of the possible: relationship management in power regimes and supply chains. Supply Chain Manag. An Int. J. 9, 346–356. doi:10.1108/13598540410560739

Cox, A., 2001a. The power perspective in procurement and supply management. J. Supply Chain Manag. 37, 4–7. doi:10.1111/j.1745-493X.2001.tb00093.x

Cox, A., 2001b. Understanding buyer and supplier power : A framework for procurement and suppy competence. J. Supply Chain Manag. 37, 8–15. doi:10.1111/j.1745-493X.2001.tb00094.x

Cox, A., 1999. Power, value and supply chain management. Supply Chain Manag. An Int. J. 4, 167–175. doi:10.1108/13598549910284480

Cox, A., Ireland, P., Lonsdale, C., Sanderson, J., Watson, G., 2002. Supply chains, markets and power: Managing buyer and supplier power regimes. London.

Cox, A., Sanderson, J., Watson, G., 2001. Supply Chains and Power Regimes: Toward an Analytic Framework for Managing Extended Networks of Buyer and Supplier Relationships. J. Supply Chain Manag. 37, 28–35. doi:10.1111/j.1745-493X.2001.tb00097.x

Crook, T.R., Combs, J.G., 2007. Sources and consequences of bargaining power in supply chains. J. Oper. Manag. 25, 546–555. doi:10.1016/j.jom.2006.05.008

Daft, R.L., Weick, K.E., 1984. Toward a model of organizations as interpretation systems. Acad. Manag. Rev. 9, 284–295. doi:10.5465/AMR.1984.4277657

Dewulf, J., Blengini, G.A., Pennington, D., Nuss, P., Nassar, N.T., 2016. Criticality on the international scene: quo vadis? Resour. Policy 50, 169–176. doi:10.1016/j.resourpol.2016.09.008

Duclos, S., Otto, J., Konitzer, D., 2010. Design in area of constrained resources. Mech. Eng. 132, 36–40.

Eisenhardt, K., 1989. Building Theories from Case Study Research. Acad. Manag. Rev. 14, 532–550. doi:10.5465/AMR.1989.4308385

Eisenhardt, K., Graebner, M.E., 2007. Theory Building from Cases : Opportunities and Challenges. Acad. Manag. J. 50, 25–32.

Emerson, R.M., 1962. Power-Dependence Relations. Am. Sociol. Rev. 27, 31–41.

Erdmann, L., Graedel, T.E., 2011. Criticality of non-fuel minerals: a review of major approaches and analyses. Environ. Sci. Technol. 45, 7620–30. doi:10.1021/es200563g

European Commission, 2017a. Study on the review of the list of critical raw materials, European Commissmion. doi:10.2873/876644

European Commission, 2017b. Study on the review of the list of Critical Raw Materials. Critical raw materials factsheets. doi:10.2873/49178

European Commission, 2010. Critical raw materials for the EU. Report of the Ad-hoc Working Group on Defining Critical Raw Materials.

Gaudenzi, B., Zsidisin, G.A., Hartley, J.L., Kaufmann, L., 2017. An exploration of factors influencing the choice of commodity price risk mitigation strategies. J. Purch. Supply Manag. 1–20. doi:10.1016/j.pursup.2017.01.004

Graedel, T.E., Barr, R., Chandler, C., Chase, T., Choi, J., Christoffersen, L., Friedlander, E., Henly, C., Jun, C., Nassar, N.T., Schechner, D., Warren, S., Yang, M.-Y., Zhu, C., 2012. Methodology of metal criticality determination. Environ. Sci. Technol. 46, 1063–70. doi:10.1021/es203534z

Graedel, T.E., Gunn, G., Espinoza, L.T., 2014. Metal resources , use and criticality, in: Gunn, G. (Ed.), Critical Metals Handbook. pp. 1–19.

Graedel, T.E., Reck, B.K., 2015. Six Years of Criticality Assessments: What Have We Learned So Far? J. Ind. Ecol. 20, 1–8. doi:10.1111/jiec.12305

Grewal, R., Johnson, J.L., Sarker, S., 2007. Crises in business markets: implications for interfirm linkages. J. Acad. Mark. Sci. 35, 398–416. doi:10.1007/s11747-007-0045-1

Guba, E.G., 1981. ERIC/ECTJ Annual Review Paper: Criteria for Assessing the Trustworthiness of Naturalistic Inquiries. Educ. Commun. Technol. 29, 75–91.

Heide, J.B., John, G., 1988. The Role of Dependence Balancing in Safeguarding Transaction-Specific Assets in Conventional Channel. J. Mark. 52, 20–35. doi:10.2307/1251683

Helbig, C., Wietschel, L., Thorenz, A., Tuma, A., 2016. How to evaluate raw material vulnerability - An overview. Resour. Policy 48, 13–24. doi:10.1016/j.resourpol.2016.02.003

Hirschman, E., 1986. Humanistic Inquiry in Marketing Research : Philosophy , Method , and Criteria. J. Mark. Res. 23, 237–249.

Jacobs, D., 1974. Dependency and Vulnerability : An Exchange Approach to the Control of Organizations. Adm. Sci. Q. 19, 45–59.

Jin, Y., Kim, J., Guillaume, B., 2016. Review of critical material studies. Resour. Conserv. Recycl. 113, 77–87. doi:10.1016/j.resconrec.2016.06.003

Kähkönen, A.-K., Virolainen, V.M., 2011. Sources of structural power in the context of value nets. J. Purch. Supply Manag. 17, 109–120. doi:10.1016/j.pursup.2011.01.001

Kiesler, S., Sproull, L., 1982. Managerial Response to Changing Environments : Perspectives on Problem Sensing from Social Cognition. Adm. Sci. Q. 27, 548–570.

Kolotzek, C., Helbig, C., Thorenz, A., Reller, A., Tuma, A., 2018. A company-oriented model for the assessment of raw material supply risks, environmental impact and social implications. J. Clean. Prod. 176, 566–580. doi:10.1016/j.jclepro.2017.12.162

Lapko, Y., Trucco, P., Nuur, C., 2016. The business perspective on materials criticality : Evidence from manufacturers. Resour. Policy 50, 93–107. doi:10.1016/j.resourpol.2016.09.001

Maloni, M., Benton, W.C., 2000. Power influences in the Supply Chain. J. Bus. Logist. 21, 49–73. doi:10.1017/CBO9781107415324.004

Manuj, I., Mentzer, J.T., 2008. Global supply chain risk management strategies. Int. J. Phys. Distrib. Logist. Manag. 38, 192–223. doi:10.1108/09600030810866986

Meehan, J., Wright, G.H., 2012. The origins of power in buyer-seller relationships. Ind. Mark. Manag. 41, 669–679. doi:10.1016/j.indmarman.2011.09.015

Mena, C., Humphries, A., Choi, T.Y., 2013. Toward a theory of multi-tier supply chain management. J. Supply Chain Manag. 49, 58–77. doi:10.1111/jscm.12003

Moss, R.L., Tzimas, E., Willis, P., Arendorf, J., Espinoza, L.T., Thompson, P., Chapman, A., Morley, N., Sims, E., Bryson, R., Pearson, J., Marscheider-Weidemann, F., Soulier, M., Lüllmann, A., Sartorius, C., Ostertag, K., 2013. Critical Metals in the Path towards the Decarbonisation of the EU Energy Sector. Joint Research Center, Petten, the Netherlands. doi:10.2790/46338

Mroueh, U.-M., Bacher, J., Punkkinen, H., Brunot, A., Bolin, L., Stahl, S., Bette, K., Mattes, K., Joce, C., 2014. CRM supply-chain analysis of Energy , ICT and electronics and Transport sectors. CRM_InnoNet Deliverable report D4.4.

Munson, C.L., Rosenblatt, M.J., Rosenblatt, Z., 1999. The use and abuse of power in supply chains. Bus. Horiz. 42, 55–65. doi:10.1016/S0007-6813(99)80049-4

Nieto, A., Guelly, K., Kleit, A., 2013. Addressing criticality for rare earth elements in petroleum refining: The key supply factors approach. Resour. Policy 38, 496–503. doi:10.1016/j.resourpol.2013.08.001

NRC, 2008. Minerals, Critical Minerals, and The U.S. Economy. Washington, DC.

Pfeffer, J., 1989. A resource dependence perspective on interorganizational relations, in: Mizruchi, M.S., Schwartz, M. (Eds.), Intercorporate Relations: The Structural Analysis of Business. pp. 25–55. doi:10.2307/2392995

Pfeffer, J., Salancik, G., 1978. The External Control of Organizations: A Resource Dependence Perspective. Harper & Row, New York, NY.

Rosenau-Tornow, D., Buchholz, P., Riemann, A., Wagner, M., 2009. Assessing the long-term supply risks for mineral raw materials—a combined evaluation of past and future trends. Resour. Policy 34, 161–175. doi:10.1016/j.resourpol.2009.07.001

Slowinski, G., Latimer, D., Mehlman, S., 2013. Dealing with Shortages of Critical Materials. Res. Manag. 56, 18–24. doi:10.5437/08956308X5605139

U.S. Department of Energy, 2011. Critical Materials Strategy.

U.S. Department of Energy, 2010. Critical Materials Strategy.

Wallendorf, M., Belk, R., 1989. Assessing Trustworthiness in Naturalistic Consumer Research, in: Hirschman, E. (Ed.), Interpretive Consumer Research. Provo, UT : Association for Consumer Research, pp. 69–84.

Yin, R.K., 2009. Case Study Research Design and Methods. Sage Publications, Thousand Oaks.