Geoforum 84 (2017) 368–377

Contents lists available at ScienceDirect

Geoforum

journal homepage: www.elsevier.com/locate/geoforum

Constructing criticality by classification: Expert assessments of mineral raw materials

Erika Machacek*

Department of Geosciences and Natural Resource Management, University of Copenhagen, Øster Voldgade 10, Copenhagen 1350, Denmark
Centre for Minerals and Materials (MiMa), Department of Petrology and Economic Geology, Geological Survey of Denmark and Greenland, Øster Voldgade 10, Copenhagen 1350, Denmark

ARTICLE INFO

Keywords:
Classification
Expert
Criticality
Assessment
Supply risk
Rare earth elements

ABSTRACT

This paper explores the role of expertise, the nature of criticality, and their relationship to securitisation as mineral raw materials are classified. It works with the construction of risk along the liberal logic of security to explore how "key materials" are turned into "critical materials" in the bureaucratic practice of classification: Experts construct material criticality in assessments as they allot information on the materials to the parameters of the assessment framework. In so doing, they ascribe a new set of connotations to the materials, namely supply risk, and their importance to clean energy, legitimizing a criticality discourse.

Specifically, the paper introduces a typology delineating the inferences made by the experts from their produced recommendations in the classification of rare earth element criticality. The paper argues that the classification is a specific process of constructing risk. It proposes that the expert bureaucratic practice of classification legitimizes (i) the valorisation that was made in the drafting of the assessment framework for the classification, and (ii) political operationalization when enacted that might have (non-)distributive implications for the allocation of public budget spending.

1. Introduction

Mineral raw materials are typically seen as essential components of all national economies (Lusty and Gunn, 2015; Tiess, 2010). However, with the introduction of the term critical material in the late 1930s in the US Strategic and Critical Materials Stock Piling Act, the discourse on critical raw materials, hereafter 'criticality discourse', initiated (US Public Laws, 1939). This discourse links the issue of mineral raw materials with the politics of national security, as the Act authorizes the acquisition of materials for national defence stockpiling to mitigate the supply chain risk of these materials (Humphries, 2013; US Public Laws, 1939).

The criticality discourse was revived in the 1970s and 1980s, and most recently by the US National Research Council (2008) through the *extension to non-energy minerals* where a critical mineral continues to be defined as '*one which is subject to supply risk*' (Barteková and Kemp, 2016, p. 4). In response, the European Commission ([EC], 2008) acknowledged its import dependence of high-tech metals which it pinpointed as critical *'in view of their economic value and high supply risks'*. The EC proposed to launch a European Raw Material Initiative which was to, among other, define critical raw materials. In fact, a multitude of material criticality definitions continue to be constructed on supply risk, analytically tying criticality and supply risk (Jin et al., 2016; Buijs and Sievers, 2011a, 2011b). Key to the current criticality discourse is the assessment of mineral criticality by experts.

Little is known about the role of the experts in these criticality assessments, their methods and impact on the outcome of the assessments. They work for institutions that serve the European Union [EU] and the United States [US] such as the European Commission [EC], or the US Department of Energy [US DoE]. Their assessments concern a dozen materials, and their significance for developing low-carbon, clean energy technologies such as in the EC-Joint Research Council [JRC] (2011) Report on Critical Metals in Strategic Technologies and the US Department of Energy [DoE] (2011) Critical Materials Strategy Report.

Rare earth elements (REEs) have been assessed as critical in both of these reports. The REEs count 15 elements of the lanthanides series in the periodic table, and scandium and yttrium (IUPAC, 2005). Their name is suggestive of rarity, while they are not (Ulmanns, 2005). Rather rare, however, is the successful separation of a REE-bearing mineral into its 16 individual REEs that can be used by industry, a competence that China holds as near-monopoly producer of more than

* Corresponding author at: MiMa, Geological Survey of Denmark and Greenland, Øster Voldgade 10, Copenhagen 1350, Denmark.
E-mail addresses: em@geus.dk, machacek.erika@gmail.com.

http://dx.doi.org/10.1016/j.geoforum.2017.03.028
Received 2 June 2016; Received in revised form 24 March 2017; Accepted 27 March 2017
Available online 11 April 2017
0016-7185/

80% of the global REE supply in 2016 (Castilloux, 2016).

Resource nationalism observed in China that arguably serves to advance value-added industrial development, is exacerbated by domestic plans of REE industry consolidation, and changes in export policies which restrict REE-flows (Wübbeke, 2013, 2015). These policies advance resource nationalism as they aim to tie geological occurrences of REE and their supply to domestic economic activities. This development and the REE price peaks of 2011 that importers experienced when China used REE as a political tool in its claims to the Japanese controlled Senkaku islands in the East China Sea in 2010, raises concerns about access to REE for import-dependent nations, and make the REEs flagship minerals of the criticality discourse (Barteková and Kemp, 2016; Kiggins, 2015; US EIA, 2014; Mancheri et al., 2013; Erdmann and Graedel, 2011).

Experts play a particular role in this criticality discourse: By assessing minerals through allotting information to the parameters of supply risk and importance to clean energy in a framework that has been designed for the assessment of mineral criticality, they legitimize these, and construct criticality. In so doing, they translate a 'key material' into a 'critical material' by means of classification according to these parameters. They experts also cross the science-policy boundary, using their authority and knowledge, and engaging politically.

Expert authority is crucial in this process, as it functions as legitimation (i) of the parameters of the assessment framework which valorises select aspects (supply risk and importance to clean energy), and (ii) of the recommendations on approaches to mitigating the supply risk, the principal objective of the assessments (Berling and Bueger, 2015; Jin et al., 2016). Through their classification, experts valorize some aspects of the minerals above others and they recommend actions such as research on REE occurrences, production, substitutability and recyclability to be funded by institutions in the EU or the US (EURARE (NERC, 2016); Innovation Metal Corp. [IMC], 2011–2013). They are, thus, complicit in decision-making on the distribution of public wealth, when their recommendations are enacted, as will be explored further on in this paper.

This paper is situated in political and resource geography through its focus on contributing to the discourse that Barry (2013) captured as 'material politics' and it draws on constructivist security studies, especially in relation to the so-called Paris School (Bigo, 2002; Balzacq, 2011a) to explore the role of experts in constructing the criticality of minerals. Its aim is to shed light on the expert role in mineral assessments, and their bureaucratic practice of classification (Bowker and Star, 2000). The paper draws on the liberal logic of security (van Munster, 2009) to unveil how expert assessments, and mineral criticality, are tied to securitization by risk profiling, without necessarily invoking security (van Munster, 2009; Bigo, 2002). It puts forward two propositions:

First, experts are essential in the construction of the meaning of criticality. They legitimize the parameters of the assessment framework, supply risk and importance to clean energy, and valorise it. This occurs as they allot information to the framework in a process of *classification* (Bowker and Star, 2000) that involves risk profiling (van Munster, 2009). The political impact of these expert practices is profound. Through the process of *valorisation*, some things are silenced, such as the geopolitical and economic antecedents to the formation of quasi-monopolistic supply scenarios by one country (policy and regulation, and market competition centred on price), and others are emphasized, such as the territorial focus of geological occurrence, metallurgical- and further processing (Bowker and Star, 2000). The technical dimension in the construction of criticality is at the centre-stage and manoeuvres experts into a position of authority to legitimize this discourse. This is a domain of politics that remains understudied. Likewise, Bakker and Bridge (2006) have argued that the concept of 'construction' is worthwhile revisiting as part of a revival of 'materiality' in human and resource geographies.

Second, the assessments of criticality, when *put to work as a bureaucratic practice* of managing risk along the liberal logic of security, pervade government and society and enable *operationalization*, as attention of policy makers is drawn to specific issues, making new links between the governance of resources, economic development, energy technologies, and national security, and funds can be mobilized to mitigate criticality. This speaks to the 'performative quality', namely 'the political work' that the construct performs, on behalf of its designers, the experts, as bureaucratic practice is put to work (Bridge, 2015). From that I propose that experts are complicit in the redistribution of public wealth toward particular beneficiaries. I conceptualize public wealth here as the percentage-share of gross national income that EU member states contribute to the EU budget. I argue the case for public wealth on the grounds of the EU budget allocation to numerous fields of action, including to research, which are in principle destined to nurture wealth through growth and innovation.

The paper is structured into five sections: The next section describes the theoretical framework. In section three the methodology and data are described. The analysis is presented in section four, jointly with the recommendations put forward in the criticality assessment, and the typology of inferences that I derive from it. The paper concludes with a discussion of the meaning of constructing a mineral as critical in section five.

2. Theoretical framework

In the following subsections, I first describe the origins of the mineral criticality discourse, linking energy (supply) security with mineral criticality, and discussing how risk (of a disruption of supply) bridges these separate but intertwined discourses. The primary concern of energy security rests with hydrocarbons (i.e. oil), in contrast to the emphasis of the criticality discourse on non-energy minerals. This backdrop serves as foundation when I turn to the theoretical discussion of the expert role in securitizing in Section 2.2, where I discuss the *Copenhagen School* and the *Paris School* to draw on the latter, and the *liberal logic of security* to explore the role of experts in constructing the criticality of minerals. In Section 2.3, I turn to the potency of classification with a view to valorisation and operationalization.

2.1. From energy (supply) security to mineral criticality

The literature on supply risk which originated in the late 1930s was augmented during the oil and cobalt crisis in the 1970s, and constitutes the backbone of the current criticality discourses. The 1973 Arab oil embargo triggered the establishment of an energy security system against the disruption of oil supply, historically tying energy security to oil supply. Yergin (2006) described three principles of energy security, namely (i) diversification of supply, (ii) resilience, which refers to a margin or buffer against disruptions, and (iii) the recognition of integration, describing one market that consists of a complex, worldwide system.

Yergin (2006) emphasized that security was to be understood as the stability of this market. The most recent definition of energy security by the International Energy Agency [IEA] reads as '*the uninterrupted availability of energy sources at an affordable price*' (OECD/IEA, 2016). This definition also has a long-term energy security dimension that centres on investments to ensure energy supply, and a short-term dimension with a focus on the reactiveness of the energy system on exposure to distortions, namely 'sudden changes within the supply-demand balance' (OECD/IEA, 2014, p. 13).

Risk (of a disruption) links the definitions of *energy security and non-energy mineral criticality*: Energy security is fundamentally concerned with the management of risk – be it of supply that might be interrupted or unavailable, capacity that might be insufficient to meet demand, prices that might be unaffordable or sources that are unsustainable to rely on. Causes for these risks might be found in energy market instabilities, technical failures or physical security threats (IEA, 2007 in Chester, 2010).

The concerns that define energy security align with those that underpin mineral criticality. The term 'criticality', thus, signifies 'importance' or 'risk', as illustrated on the reasons used for classifying some minerals to be of higher criticality than others. These reasons include the technological demand for the minerals, from which the higher importance of some minerals and their availability is deduced. Put differently, the risk of not being able to access sufficient volumes in a timely manner at reasonable prices might put the production of particular technologies in certain geographical areas that without local mineral access and processing facilities at risk (US DOE, 2011).

Importantly, in much the same way a resource is constructed through 'continual discursive boundary work' (Bakker and Bridge, 2006; Bridge, 2001, p. 2154), so is the construct of 'criticality' in the work by experts. Erdmann and Graedel (2011, p. 7628) observe that '(…) the criticality of REEs is *currently singled out* because of the rapid diffusion of renewable energy and electric cars [which] will drive demand, and actual supply is largely concentrated in China.' From that, and the findings of the US National Academy of Sciences [NAS] study (2008, p. 9) that '*all minerals and mineral products could be or could become critical to some degree, depending on their importance and availability*' it can be claimed that the *criticality of a mineral is a dynamic concept* which is closely tied to the processes of enabling access to and availability of the minerals.

2.2. Experts and the liberal logic of security

Experts are central to the construction of criticality through their assessments. They represent a type of authority that holds certain knowledge, and they are expected to come forward with recommendations to be accepted as credible and authoritative by the public (Boswell, 2009; Berling and Bueger, 2015). Authority is "a political concept" and despite an absence of politically/democratically "electing" experts, which would make them politically accountable, they "nevertheless exercise authority-like powers over questions of true belief" (Turner, 2001, p. 128; Müller and Hochmüller, this issue).

To some extent limited by their institutions, experts exercise the power of authority according to their individual subjectivity which defines how they interact with policy-makers, security practitioners, and governed subjects (see Rychnovská et al., forthcoming). The mode of interaction affects how the expertise of experts informs governmental practices and impacts the choice of some policy options over others. Mineral criticality assessments by experts are conducted in the presence of uncertainties, specifically as to how to address the complex interwoven issues at hand (Prior et al., 2013; Bridge, 2000), and which actions to take. The weighing-in of scientists as experts in decision-making processes has the scientists mediate uncertainties as to the knowledge available and produced (Jasanoff, 2005).

In this paper, I draw on the notion of securitization, which offers a radically constructivist perspective on how security issues are constructed (Wæver, 1995; Buzan et al., 1998; Balzacq, 2011a,b). In its original conceptualization, securitization was defined as 'speech act' (Wæver, 1995, drawing on Austin), as opposed to the traditional conceptualization of security as military strength (Walt, 1991). Securitization not only changes the meaning of political issues, but it also shapes the role of social actors and institutions, typically by empowering some, while marginalizing others. This dynamic of changing meanings of political issues, and of the role of actors and institutions through securitization can be – and often is – affected by the activities of scientists and specific types of knowledge to policy-makers (Berling, 2011). How such actors transgress the boundaries of science and politics and how they obtain the status of recognized security experts has recently become subject to new inquiry (Rychnovská et al., forthcoming; Berling and Bueger, forthcoming; cf. also Gieryn, 1983).

The *Copenhagen School* highlights the role of language used by so-called securitizing actors – typically political elites – in a process of securitization (Buzan et al., 1998). If the audience accepts the securitizing speech act, the securitizing actors receive approval to use extraordinary measures, legitimized by intentionally invoking a security threat in a discourse. The use of extraordinary measures denies the politicization of the given problem, i.e. the possibility of an open democratic deliberation on different ways on how to address the problem. Securitizing moves might be strengthened or weakened by certain conditions external to the speech act (Buzan et al., 1998). The securitizing actor has a key role in presenting an issue as a security matter, and in so doing, in obtaining public acceptance for a reaction that might be considered exceptional given the issue (Buzan et al., 1998).

In contrast, the *Paris School* emphasizes the role of "mundane" bureaucratic processes and the work of experts engaging in the production of security knowledge and executing security practically (Bigo, 1996, 2001; Balzacq, 2011a,b). From this perspective, threats, risks, and insecurities are not necessarily a product of political speech acts, which legitimize emergency measures, but are more often a result of the work of security professionals and the mundane, routinized security practices (i.e. airport screening, CCTV surveillance) that construct some social groups or activities as dangerous and thus shape the notion of (in)security in our daily lives. 'The productive power of the practice of professionals', and their generation of 'systems of meaning' are central to this School, and challenges the conceptualization of the sequential approach to securitization of a speech followed by physical action.

Apart from the differences in understanding how (in)security is constructed, the Paris School pays more attention to the underlying logic of risk management in the governance of security. An important aspect highlighted e.g. by van Munster (2009) is that the logic of risk is increasingly applied in the contemporary governance of unease (i.e. the notion that an act of terror is possible at any point in time, and not necessarily preventable). This logic of risk draws on neoliberal governmentality and the circulation of goods, services and people, central to this ideology. How desired and undesired circulations are distinguished and how the "dangerous" and potentially harmful circulations are regulated becomes a matter of risk management, which is often in the hands of various experts and security bureaucrats. Balancing the freedom of circulation of goods with restricting the circulations that may bring "insecurity" may come in different forms, from the profiling of people or minerals, to the politics of sanctions.

This paper argues that a specific model consisting of factors that represent a threat, risk profiling and risk management (see Table 1), helps construct the notion of security and insecurity at the level of mineral raw material classification. More specifically, classification serves to legitimize (supply) risk and importance to clean energy

Table 1
Two logics of security: political realism v. liberalism.

Political realism	Liberalism
Representation of threat	
Friend/enemy opposition	Friend/enemy continuum
Personification of the enemy	Impersonal correlation of factors liable to produce risk
Measures/strategy	
Exceptional measures that bypass normal political procedures	Normal measures such as surveillance and risk profiling
Measures counteract existential threat	Measures contribute to the social control of larger populations
Objective	
Elimination of threat	Freedom
The elimination of a threat secures the collective survival of a socio-political order	Management of risks secures the circulation of goods, persons and capital

Source: van Munster, 2009, p. 10.

technology in the construction of criticality. Clean energy technology is arguably selected due to its universal significance for obtaining a competitive advantage in the global market, in addition to such a focus providing opportunity for technological advances. As illustrated in Table 1, and according to van Munster (2009), the *threat* is represented by the *'impersonal correlation of factors liable to produce risk'* which will be operationalized in this paper by exploring how experts correlate the parameters of the criticality assessment by i.e. allotting information on the REE neodymium to supply risk and importance to clean energy of the assessment framework. This serves to illustrate how their classification practice legitimizes the valorisation enacted in the framework and how it enables the legitimization of risk.

Here, the argument works with Abrahamsen (2005) who argued that *issues may first be risks* before they are shown as threats. She demonstrated gradations or continuums of 'risk/threat' rather than a momentous shift from what was a political issue to a security issue (Abrahamsen, 2005). This is an important concept when issues are discussed that have an economic-political dimension, such as minerals which can be critical for economic activity and strategic for national defence (Grasso, 2013; Hurst, 2010; Hedrick, 2004).

The paper moves on to the *measures* taken in the liberal logic of security to respond to the threat, and discusses *'normal measures'* such as *risk profiling*, as listed in Table 1, and distinct to the exceptional measures that bypass normal political procedures (Van Munster, 2009). This positions the paper closely to the *Paris School* which has demonstrated that 'normal measures' can also form part of securitization, as distinct to the predominant emphasis of exceptional measures in the *Copenhagen School*. The risk profiling is examined through expert assessment based on the prior bureaucratic practice of classification as information on minerals was allotted to the parameters (supply risk, importance to clean energy) of the assessment framework.

Then the paper turns to the *objective* of the liberal logic of security, which is to *manage a risk* rather than eliminating a threat. As Table 1 outlines, risk management in the liberal logic can concern the *circulation of goods* which can include mineral products. This objective is rather distinct to that of securing a socio-political order (Van Munster, 2009), as it arguably constitutes an antecedent, with economic activity as pillar for any socio-political order. The paper operationalizes this part by examining the expert recommendations on how to manage mineral criticality, and by pointing to projects which were funded that appear to respond to some of the recommendations produced. To be explicit, while working with the processes of constructing risk and threat, preceding securitization, the paper remains at the level of these processes despite drawing on the concept of bureaucratic practice from securitization.

2.3. Potency of classification: valorisation and operationalization

Classification is a potent process of silencing and valorising (Bowker and Star, 2000). By framing the discourse of criticality in technical terms, geologists and material scientists are catapulted into a position of authority in the political field (Berling, 2011, p. 392). These actors are typically undisputed experts in questions that evolve around minerals and materiality, which is in stark contrast to the contested legitimacy of particular expertise on topics such as climate change. By establishing a relation between a particular mineral and risk, and framing it in technical terms, experts create (undisputed) certainty about the relations between supply risk and importance to clean energy: mineral criticality. They also infuse materials with a political life, as they make them 'a matter of collective importance' when they place them centre stage, as illustrated by Barry (2013).

As a mineral is rendered critical by experts, by means of construction (Bridge, 2001), it is made a subject of a particular category which *'valorises some point of view and silences another'* (Bowker and Star, 2000). In essence, the experts legitimize and valorise the category which has already been elaborated as the assessment framework and methodology were designed by experts of the US National Academy of Sciences (NAS) for the US, and by experts of the Joint Research Centre (JRC), Oakdene Hollins Ltd, and The Hague Centre for Strategic Studies for the EU, respectively, prior or at the time of the assessment. These processes represent 'an ethical choice', as '*for any individual, group or situation, classifications and standards give advantage or they give suffering*' (Bowker and Star, 2000). Hence, criticality, as a particular construct, and category, has a valorising ability (Bowker and Star, 2000).

The criticality construct has political operationalization, which is made visible by the funding of particular initiatives to 'counteract' mineral criticality. In a market-based system criticality concerns would have been perceived as essentially economic, thus, to be addressed by businesses. Thus, funding of supply risk mitigating initiatives would have been considered as interventionist, with opinions divided as to whether such would be useful in the case of rare earth elements (Zachmann, 2010; Dobransky, 2015). Yet the potency of 'criticality' emerges from combining supply risk with importance to clean energy, which provides an indication of a political issue (and threat). This conceptualization speaks to the 'performative quality', namely 'the political work' that the construct performs, which Bridge (2015, p. 329) elaborated on in the case of energy security.

Based on the elaboration above, the classification of minerals as critical matters for at least two reasons: (i) it valorises the importance of the supply of particular minerals for economic activity, and (ii) it allows for the economic parameters (i.e. supply risk and importance to clean energy (Barteková and Kemp, 2016, p. 6)) to be abstracted to a construct, 'criticality', that is operational at the political level. It can be deduced that the construct of criticality is tied to *valorisation and political operationalization* by expert practice of classification with benefits for particular interest groups: research and development, and firms which make use of these minerals. To unpack how I analyse this valorisation and operationalization, I proceed in section 3 with an outline of the methodology.

3. Methodology and data

In this section, I describe the methodology applied in this paper, and I discuss the data used which stems from the methodology and recommendation sections of the report on Critical Metals in Strategic Energy Technologies by the European Commission and the Joint Research Council [EC-JRC, 2011] and of the report on the Critical Materials Strategy by the US Department of Energy [US DoE, 2011], hereafter also referred to as criticality assessments. To examine how the concept of criticality has been constructed, I draw on (i) the information (secondary data and interviews with respondents from industry) that experts have used in their assessments of the minerals which is published and available in the reports in a condensed version, and (ii) the texts that the experts have produced as they (a) classify this data and (b) provide recommendations.

The two reports are key sources in the extensive literature on criticality assessments (Jin et al., 2016), as they are issued by institutional bodies which have a clear political role in the EU and in the US, by conducting science for policy (EC, 2016a; Arstechnica, 2017), and they draw on a pool of experts. Both reports display a number of similarities: They are technical, and they draw on supply risk, and importance to clean energy as parameters. Both reports assess the REE neodymium as critical, and both reports provide recommendations based on it.

The methodology section of the US DoE (2011) Critical Materials Strategy (Chapter 5, Appendix A) originates from the conceptual methodology developed in the Minerals, Critical Minerals and the 2008 US Economy Study conducted by the US National Academy of Sciences (NAS). The conceptual methodology of NAS centres on two dimensions: "Importance to Clean Energy" (modified from "Impact of Supply Disruption"), and "Supply Risk" with a modification of the attributes that characterize this dimension. The report highlights that *'the materials of interest examined in the report will be referred to as "key materials", until the criticality assessment is presented'.* (NAS, 2008, emphasis added) The EC-JRC (2011) assessment evaluates 14 metals which are considered key to the deployment of the six low-carbon energy technologies including nuclear, solar, wind, bio-energy, carbon capture and storage (CCS) and electricity grids. The methodology of the EC-JRC (2011, p. 18) Critical Metals in Strategic Energy Technologies assessment report builds on four criteria.

The methodology of this paper focuses solely on the parameter 'supply risk' of the methodologies of these reports, and neodymium, which represent a dimension and focus element, respectively, that cut across the US DoE (2011) and EC-JRC (2011) reports. This selection enables a comparison of the two criticality assessments which serves several purposes: (i) to explore similarities and differences in the *construction of criticality* by the experts as they engage in the bureaucratic practice of classifying by profiling risk, (ii) to more rigorously underpin the *proposition of valorisation* by classification that this paper puts forward. This is achieved as it illustrates how questions of value have been addressed, and as it unveils whether and how value questions have been silenced, next to (iii) illustrating how the criticality construct has *potential for political operationalization*.

4. Analysis

In this analysis, I connect the mineral risk assessments and criticality classification to the materiality discourse that cuts across political and resource geography (Bakker and Bridge, 2006; Barry, 2013; Bridge, 2009). The analysis is structured according to *representation of threat – measures/strategy – objective* pursuant to the liberal logic of security described in Table 1 (Van Munster, 2009). First, the *representation of threat* is elaborated. This involves the analysis of the factors, which are stipulated as 'attributes' to the 'dimensions' in the US DoE (2011) report, and as 'criteria' to the 'factors' in the EC-JRC (2011) report. Second, the *normal measure of risk profiling* is analysed by examining the supply risk assessment, resulting from the bureaucratic practice of classification by means of allotting information to the 'attributes' and 'criteria', and inferences made, which I categorize in a typology. Third, the *objective* of the liberal logic of security to manage risk is explored through an analysis of the expert recommendations. In the following, I elaborate further:

4.1. Producing risk

In the liberal logic of security, the *representation of threat* refers to the *'impersonal correlation of factors liable to produce risk'* (Van Munster, 2009, p. 10). This follows Abrahamsen (2005) who argues that risk-threat might precede security. Further, Kiggins (2015, p. 5) emphasizes that *'thinking through the problem of risk (threat) associated with rare earths is assisted by utilizing security as a conceptual framework'*. The construction of risk features explicitly in the assessment frameworks of the reports, and is driven by factors which I explore in the following:

The US DoE (2011, p.115) report characterizes the 'supply risk' dimension with five attributes which are weighed as illustrated in Fig. 1a. In contrast, the EC-JRC (2011) assessment evaluates bottleneck risks from a supply chain perspective, using four criteria shown in Fig. 1b. In a comparison of the production of risk by the factors used in two reports the following can be observed:

While the attributes and criteria of the reports broadly appear to match, significant differences can be mapped that affect the production of risk, specifically supply risk. Outnumbered by one additional attribute in the US DoE report, the EC-JRC report makes no reference to 'basic availability', thus, geological occurrence. The rhetoric chosen with the attributes of the US DoE report may be suggestive of an inward-looking strategy, i.e. a domestic focus with mineral self-sufficiency for supply. This is illustrated both with 'basic availability' and 'co-dependence on other markets' for supply, and contrasted by no such reference to availability and 'cross-country concentration of supply' in the EC-JRC report.

The presence and absence of numerical weighing of the attributes and criteria in the US DoE and the EC-JRC reports, respectively, reflects this inward-looking, self-sufficiency strategy pursued by the US DoE report, along with the relative importance allotted to constructing the risk. For instance, 'basic availability' is weighed at 40% of the total supply risk in the US DoE report, while it is, as just described, absent from the EC-JRC report. Arguably, a 40% weighing in the correlation of factors to produce risk in the US DoE report suggests the relative importance attributed to domestic geological occurrences.

The overarching classification of the EC-JRC report criteria of the low and top left shares of the pie chart into 'political factors', and from low and top right into 'market factors', is suggestive of risk being either politically- or market-constructed, even if correlated. A social science approach could emphasize markets and political institutions as socially constructed. It would be likely to focus on another level and unit of analysis, in which disciplinary discourses including within geography i.e. on actor-network analysis would have much to contribute.

Yet, and importantly, the supply risk construction in the EC-JRC report addresses both the limitations to expanding supply, broadly termed to enable further exploration, and the political risks associated with key suppliers. Surprisingly, here the US DoE report centres solely on producer diversity. It is worth noting that rhetorically the choice of 'producer diversity' might be more conducive to the construction of security as it works with the pendant of 'producer concentration' to which monopoly production is easily linked. One might argue that the risk is almost inherently attached to this choice of terminology, and the processes leading to a producer concentration are thereby silenced. These processes include decision-making on material prices e.g. without consideration of wider environmental and economic effects, trade negotiations, and many more, which ultimately define market- and governance structures. Overall, whether the construction of supply risk benefits most from the EC-JRC or the US DoE approach is debatable and subjective to the perspective of the experts in authority.

4.2. Risk profiling: The role of science in authoritative silencing

The *normal measure of risk profiling*, or risk management, through which certain notions of danger and unease are constructed, draws heavily on practices that are deemed "normal", "mundane", and without many controversies (cf. van Munster, 2009). In the governance of REE, such mundane, normal measures that contribute to "risk profiling" are typically the criticality ratings. These ratings are produced in the mineral assessment, in which experts collect and classify information on Nd from interviews with respondents from industry and from secondary sources for the supply risk attributes and criteria, in the US DoE (2011) and EC-JRC (2011) reports respectively, as illustrated in Table 2.

The REE neodymium (Nd) has been chosen here for its criticality ranking among the critical elements in both the short and medium term (US DoE report) and among the five metals of the 14 metals assessed that demonstrate a high supply risk (EC-JRC report). Neodymium metal is used among other in alloys to make high-strength magnets, including for certain types of wind turbines, and for permanent magnet motors with a diverse range of applications including from the automotive industry to wireless-tools.

The two reports reveal many commonalities, such as of different technology uptake and technology mix scenarios modelled, and of the types of indicators used for assessing supply risk (addressed in the 'Bottleneck Screening of the EC-JRC (2011) study). Yet, differences pertain to technologies addressed with overlaps in solar and wind, and applied methodologies:

The US DoE (2011) study begins with a list of metals to be discussed, while the EC-JRC (2011) uses a bottom-up approach to 'quantify each of the metal requirements' for a given technology

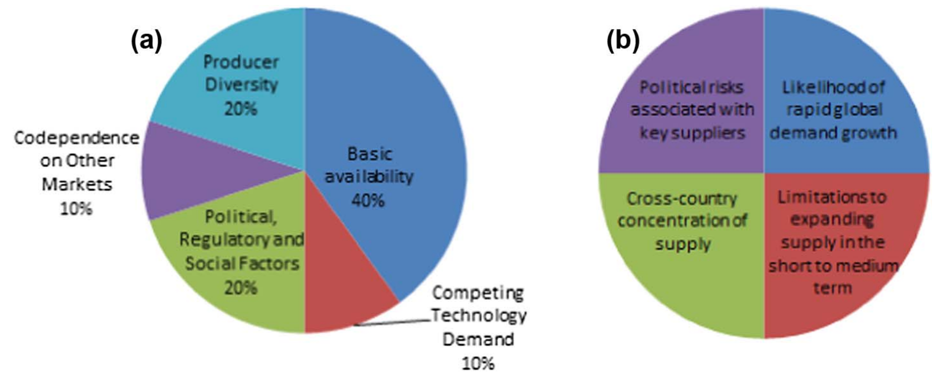

Fig. 1. a (left). US DoE (2011) Supply risk attributes. Source: US DoE, 2011, p. 115; b (right). EC–JRC (2011) criteria for assessing the supply chain bottlenecks. *Source:* EC-JRC, 2011.

scenario. This is an indicator of a valorisation: By beginning with a list of metals, certain metals have already been excluded (silenced) from the outset (based on results from the 2010 Critical Material Strategy) while others are emphasized. Among the emphasized are rare earth metals for reasons described as the value of their properties. This is where the technical level of the report becomes apparent, as magnetic, and optical and catalyst properties are cited, and the periodic table is referenced (US DoE, 2011, p. 9).

Through the entry point of metals, natural scientists are prompted as authorities in the mineral criticality discourse. Against their methodological predisposition in preference of measurable/quantifiable criteria such as elemental characteristics, volume supply and price, it is unsurprising that the risk profiling has focused on these aspects, as reflected in the information fed into Table 2. For instance, in the supply risk assessment, reference is made to *'new non-Chinese mines'* that *'will increase* [producer] *diversity significantly by 2015'* (see table 2, US DoE (2011), 'producer diversity'). However, this perspective silences risk-profiling of strategic considerations that remain strengths of social science, such as of investor motivations to fund non-Chinese mines without which no new mines will be opened or constructed. Their strategic considerations are key to adequately assessing the supply risk. In contrast, the EC-JRC (2011) information on 'limitations to expanding production capacity' pointed to *'long lead times and complex commercial and technical challenges involved in bringing a rare earth mine to production'* which highlights the underlying factors that accompany supply risk.

Simultaneously, by emphasis of 'non-Chinese mines' in the information allotted in the US DoE report the focus is clearly geographical, and geo-political, and thus, on the scientific investigations of geographers and political scientists, among other social scientists. However, by methodological choice this mineral criticality discourse takes a natural science turn – and valorises materialized above non-materialized characteristics. Arguably, this is a surprising turn following the established understanding that mineral criticality is dynamic.

To exemplify this natural science turn further, I draw on the supply risk criterion 'basic availability': The allotted information indicates that

Table 2
Supply risk assessments by experts from US DoE (2011) and EC-JRC (2011) for neodymium (Nd).

US DoE, 2011 Supply Risk	Short term Medium term	3 3	Information (Sources: GE, 2010; USGS, 2009 in US DoE, 2011)
Basic availability (40%)	Short term Medium term	2 3	Nd had limited near-term flexibility for increasing global supply, despite stockpiled supplies. Demand for NdFeB magnets is likely to exceed producers' ability in the short term. Recycling magnets is of great interest; investments in research and development toward overcoming technological challenges are needed
Competing technology demand (10%)	Short term Medium term	3 2	The majority of global consumption of Nd oxide in 2010 was for high-strength magnet applications; only a small portion was for wind generators and hybrid vehicles. Magnetic refrigeration and PM motors for home applications could increase demand for NdFeB magnets beyond the medium term
Political, regulatory, and social factors (20%)	Short term Medium term	3 3	Nd is predominantly produced in China, which has instituted significant export quotas and tariffs on REEs for resource conservation and environmental regulatory reasons. New mines in Australia and the US will provide additional supply, but are subject to strict permitting processes and environmental regulations
Codependence on other markets (10%)	Short term Medium term	2 2	Nd's moderate abundance and prices compared to other REEs leads to high revenue streams. Nd usually drives production of other REEs
Producer diversity (20%)	Short term Medium term	4 3	Nd is mainly produced from mines in China. New non-Chinese mines will increase diversity significantly by 2015, even though global supply is projected to remain tight
Source: Data compiled from US DoE, 2011, p. 146			
EC-JRC, 2011 Supply risk	Overall risk	High	Information (Sources: IMCOA, 2010; Failed State Index, 2009; Worldwide Governance Indicator, 2009 in EC-JRC, 2011)
Likelihood of rapid demand growth		High	Demand growth for Nd is forecast to be very strong by industry sources, due to competing pressures for rare earth magnets. The likelihood for rapid global demand growth over the coming five to ten years is therefore scored as high
Limitations to expanding production capacity		Medium	There are considerable reserves available and several rare earths projects under development. Nonetheless the limitations to expand Nd production in the short to medium term are scored as medium, due to the long lead times and complex commercial and technical challenges involved in bringing a rare earth mine to production (comparison to Dy)
Concentration of supply		High	Nd production is concentrated almost entirely in China, a country scoring high on political risk indicators. As a result, both the concentration of supply as well as political risks are evaluated as high
Political risk related to major supplying countries		High	

Source: Data compiled from EC-JRC, 2011, p. 44 and p. 48.

'*recycling of* [NdFeB] *magnets is of great interest*' and the need for investment in R & D to overcoming technological challenges is emphasized. Clearly, this risk profiling takes a 'material' turn by emphasizing a process and technology. It lacks the qualitative dimension of e.g. how material loops can be closed, namely through understanding what different actors can gain from closing material loops, and, in essence, what their incentive is to pursue recycling efforts beyond often timely-constrained, publicly-funded recycling schemes.

Risk profiling is inherently selective and filters from the perspective of the methodological choices of the authorized scientific experts of this discourse. To which extent this selectiveness has a bearing on the assessment will be discussed in the following sections where I will explore whether inferences have been made from the information (REE-data) that was fed into and allotted to the parameters of the framework (attributes of the supply risk criterion) during the expert assessment.

4.2.1. Inferences in the assessment of neodymium criticality

I examine whether these inferences involved references to a perceived need for securitizing mineral criticality, according to the liberal logic of security and I respond to the proposition of *political operationalization* of the criticality construct. Inference is defined here as *"the process of deriving the strict logical consequences of assumed premises"*. The exploration of the policy recommendations in these two reports allows for exploring what consequences have been derived from the premises. Here the understanding is that recommendations by the experts are inferences, and allotted information presents premises, namely statements that underpin the criticality assessment. The focus is specifically on inferences related to supply risk, on the case of both reports, and neodymium (Nd). The operationalization occurs as the recommendations are implemented by political action, arguably with implications for how public wealth is distributed, that I will explore further on.

The allotted REE-data which was subjected to classification (Table 2), serves to translate expert assessment into policy recommendations (EC-JRC, 2011; US DoE, 2011). The types of delineated recommendations from the US DOE (2011) and the EC-JRC (2011) reports warrant exploration. Broadly summarizing, as in Table 3, the inferences are to ensure a reliable supply of ore at competitive prices to European and US industrial players in order to 'support and sustain the existing rare earths supply chain'.

The EC-JRC report (2011) describes a range of potential mitigation strategies, which span from expanding European output, increasing recycling and reuse to reducing waste and finding substitutes for these metals in their main applications. One of the broad recommendations refers specifically to REE as it advocates research and development, and demonstration projects on new lower cost separation processes, particularly those from by-product or tailings containing REE. The specific recommendations call for more data collection and better provision of information on the demand, supply and price trends for metals with i.e. feasibility studies, research and development including demonstration projects for separation processes, collaboration with other countries that share the risk agenda which is also to involve an exchange of information, as well as recommendations to fund before-mentioned activities.

4.2.2. Typology of inferences

The information that experts have assigned to the supply risk criterion as shown in Table 2 is connected to the expert recommendations (inferences) based on that information in Table 3. I identify four types of inferences which reflect the methodological choices made which were endorsed by the experts as they engaged in the assessment and as they allotted information on particular minerals to the parameters of the assessment framework. As the experts classified, minerals ceased to be only 'key materials' with geological characteristics; they are now 'critical materials/minerals' and their circulation (access and availability in particular) needs to be secured.

I exemplify this argument through a case: The experts assigned information (premise) 'complex commercial and technical challenges are involved' to the criterion of 'Limitations to expanding production capacity' (EC-JRC, 2011, see Table 2), which points to a risk that substantiates the criterion of the assessment framework. From that, experts make the inference (recommendation) to 'support research and development as well as demonstration projects', an *inference of a material nature*. The information attributed to the criterion mobilizes the risk of production and thereby enables, through the inference, a mode to put the bureaucratic practice of classification to work via political operationalization: As the production capacity criterion is tied to criticality, is ceases to be solely economic and becomes also a political concern, flows of funds to support demonstration projects could be mobilized. This will be further elaborated in the next

Table 3
Typology of inferences/recommendations made by the experts.

Examples of inferences/recommendations made by the experts	Types of inferences	Projects funded* (selection)
Co-funding encouraged of feasibility studies conducted by junior miners incl. with specific recommendation of EBRD	Financial inference	Critical Material Institute ([CMI], 2016) (US DoD funded)
Funding for innovative design for disassembly		
Funding of demonstration projects in hard disc drive and flat panel display disassembly and recycling		
Invest broadly in alternative technologies (e.g. for wind turbines) to substitute for technologies relying heavily on bottleneck metals		
Ensure reliable supply of *ore concentrates*	Material inference	CRM_Innonet (2016) (EC-funded)
R & D and demo- projects on new, lower-cost separation processes particularly those from by-product or tailings containing rare earths		
Investments in research and development toward overcoming technological challenges are needed (US DOE)		ERECON (EC, 2016d) (EC-funded)
Ensure reliable supply of ore concentrates at *competitive prices*		EURARE (NERC, 2016) (EC-co-funded)
R & D and demo- projects on new, *lower-cost* separation processes particularly those from by-product or tailings containing rare earths	Economic inference	Minerals4EU (2016) (EC-co-funded)
Feasibility studies on bringing back into use and updating existing assets		
Ensure *reliable supply* of ore concentrates	Structural/geopolitical inference	
Support and sustain the existing rare earths supply chain in Europe		
Collaboration with countries/regions with a shared agenda of risk reduction		

Sources: author based on data in Table 2, highlights in italics added by the author; project websites for the projects listed.
Note:
* All entries in this column are not suggestive of an established causality between the funded projects and the recommendations of the criticality assessments; rather, they underpin the proposition of this paper that the construct of criticality enables political operationalization. An exception is the Minerals4EU (2016) project, which clearly announces that it 'is designed to meet the recommendations of the Raw Materials Initiative'.

subsection by an exploration of how the profiled risk could be managed. Overall, the typology illustrated how the expert assessment of criticality, through the practice of classification, could create momentum, in principle, via different types of inferences, for how public wealth is distributed. The measure of risk profiling has a purpose: to manage risk, to be elaborated in Section 4.3.

4.3. Managing the risk: Securing mineral circulation

The objective of the liberal logic of security is the *management of risk*, such as to secure *free circulation*, be it *of goods*, such as of minerals discussed here, or of *persons and capital* (Van Munster, 2009). The so-called normal measure of risk profiling, namely the bureaucratic practice of classification in which the experts engage as they conduct the assessments (discussed in Section 4.2), has enabled recommendations for the management of the risk. Its operationalization relies on the recommendations made by experts and occurs when these are enacted. The following examples are illustrative rather than comprehensive, and support the proposition of political operationalization, by painting an image of the potential (non-) distributive effects of the criticality classification by experts.

An example for the management of the risk of production capacity could be the EC-funded EURARE project that aims to develop a *'sustainable exploitation scheme for Europe's Rare Earth ore deposits'* (NERC, 2016), and proposes a remedy against criticality, with many more projects emerging on similar grounds. The EURARE project is discussed as it has received comparatively high EU-co-funding[1] at nine million Euro for a project period of five years, and the call to which it responds as well as its project aim align closely to the expert recommendation of the criticality assessments. The expert recommendation illustrates an economic-material inference, namely to support *'R & D and demo- projects on new, lower-cost separation processes particularly those from by-product or tailings containing rare earths.'* The project works on geological resources, mining and beneficiation, extraction and separation of the REE, and regulation, and the processing of tailings from bauxite residues for REE (NERC, 2016). Project partners include universities, geological surveys, firms involved in the processing of minerals and metals including to intermediate components such as catalysts or magnets, a consultancy firms and junior exploration firms (NERC, 2016).

Despite a lacking identifiable clear correlation between expert recommendations of the criticality assessments and the EURARE project design, it is here where bureaucratic practice of classification, put to work, and operationalized at the political level might have created momentum to fund this project. This operationalization might have redistributed public wealth to public and private interests with distributive benefits clearly more for those with (vested) interests in the participating firms and institutions as project beneficiaries. Especially the funding of research conducted by private firms might have led to new technologies, potentially to be patent-protected. Thus, a form of wealth might result from this project that arguably no longer directly benefits the public which supported this research, see Fig. 2b through the member state contribution to the EU budget, see 'GNI own resource', Fig. 2a.

Another example provided in the typology of inferences of Section 4.2 (Table 3, page 13) is the recommendation of '*collaborating with countries or regions with a shared agenda of risk* reduction, such as the US or Japan'. This constitutes, as I argue, a geopolitical inference: In the process of informing the criteria in criticality assessment, experts through their practice of gathering and allocation information to classification criteria, have reinforced that the monopoly producer, China, poses a risk to the supply of REE. The criticality assessment arguably serves to legitimize a political risk with the key supplier of the REE and manifests this by means of the recommended measure to manage this risk. This inference involves establishing or strengthening alliances by expanding them i.e. to new areas such as mineral risk management, and provides for political operationalization through recommendations.

An argument for calling for bi- or trilateral meetings of representatives from these countries has been provided. Indeed, in 2011, the EU, Japan and the US launched a trilateral dialogue to promote cooperation in the field of critical materials (EC, 2016; New Energy and Industrial Technology Development Organization [NEDO], 2014). The trilateral dialogue has been organized annually since, in Washington (October 2011), in Tokyo (March 2012), in Brussels (May 2013), and in Iowa (September 2014) (EC, 2016b, c). A trilateral workshop between representatives of these same countries has also been organized in Brussels by the EC (2013), based on *'concerns [which] have been growing over recent years concerning reliable and undistorted access to raw materials world-wide, particularly to non-energy raw materials, and on the impact restrictions to access could have on the economies of the US, Japan and the EU.'* Arguably, expert classification has potency of political operationalization, legitimized by their authority in the discourse, and technical framing, both of which are supported by the truth-speaking notion of science and manifested in the recommendations on the construct of criticality. Yet, this discourse lacks a discussion of the issues that were silenced in the risk profiling, such as antecedents to the quasi-monopolistic supply structure for some minerals. This would call for an inclusion of the scientific competences of social scientists including geographers that could shed light on global trade dynamics, and context- and space-time specific discourses which feed into strategic decision-making processes, i.e. of investors that are at the centre-stage of new mining ventures.

Yet another example is the expert recommendation of '*encouraging co-funding for feasibility studies* which traditionally exploration firms conduct, with particular mention of a *possible involvement of the European Bank for Reconstruction and Development* (EBRD)', a financial inference. In the process of informing the 'political risk with a key supplier' criterion in criticality assessment, experts qualify China as a country scoring high on political risk indicators. The information provided mobilizes the supply risk criterion. It is, however, the political ideology and aspirations of China that feature as primary concern for countries which high-tech metal supply is dependent on China, and this concern has been jointly packaged into the criticality discourse, concealed under 'supply security'. Arguably, this has potential for political operationalization and for justifying allocations of the EU budget to particular responsive activities offered by research projects. In so doing, research funding benefits arguably those groups of scientists more which have been prompted by the criticality discourse.

5. Concluding discussion: The meaning of criticality

This paper explored the role of expertise, the nature of criticality, and their relationship to securitization by tracing the bureaucratic practice of classification in which experts assume a leading role as they are authorized by a technical discourse to conduct mineral criticality assessments. With the liberal logic of security traced through representation of risk (threat), measure and objective, I have outlined how experts construct criticality by risk profiling, a form of classification.

In particular I have argued that the bureaucratic practice of classification is a means of valorisation. This comes to light at the point when experts commit to assessing minerals as they legitimize and valorise a given methodology, i.e. a pre-defined list of minerals which are to be assessed, and the given parameters in the assessment framework that serves as their basis for the assessment. The valorisation also emerges when experts allot information (from interviews with industry

[1] The EURARE project was co-funded by the European Commission (EC) under the 2012 Cooperation Work Programme for Nanotechnologies, Materials and new Production Technologiesand specifically theraw materials topic NMP.2012.4.1-1 "New environmentally friendly approaches in minerals processing".

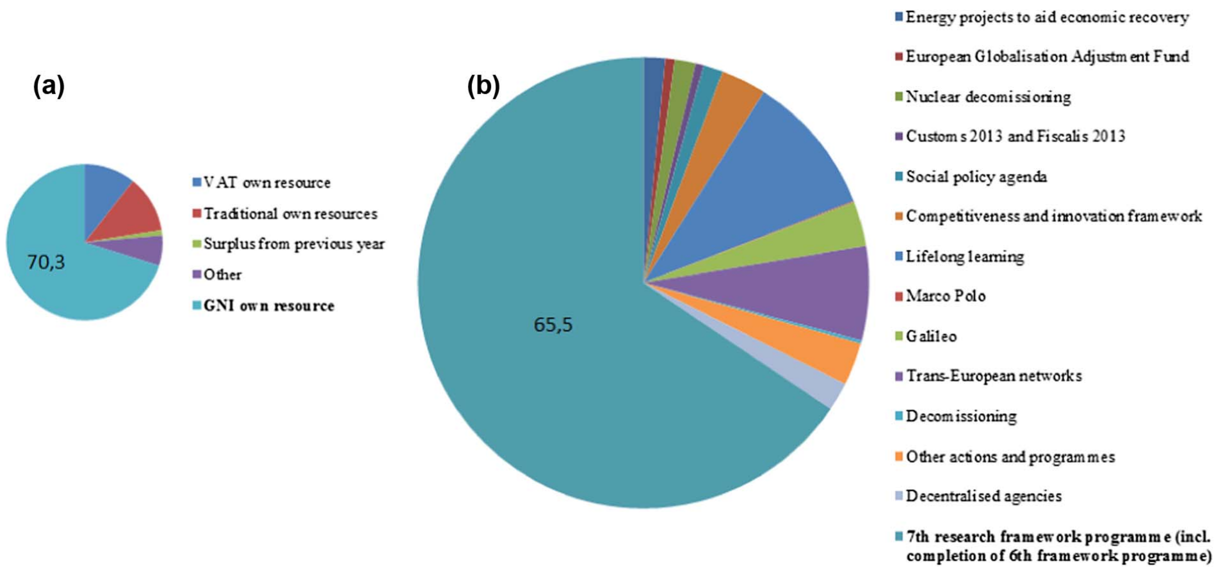

Fig. 2. a. EU budget 2012. Financial report (left); b. Implemented payments of a total of 11,969 mio. EUR under heading 1a – 'Competitiveness for growth and employment', 2007–2013 (right), of which the 7th research framework programme received 7853 mio. EUR. *Sources:* (2a) EU, 2013, p. 10; (2b) EU, 2013, p. 45. Note: Both figures indicate percentage shares.

respondents and from secondary sources) to the parameters of the framework, and construct criticality, silencing some aspects and highlighting others, i.e. by weighing.

The information allotted serves as premise for inferences (recommendations). I introduced a typology of inferences emerging from the criticality assessment of experts. These inference types serve as abstractions that enable political operationalization through the criticality classification. Specifically, when the bureaucratic practice of expert classification is put to work, the criticality construct enables political operationalization, as recommendations by the experts on how to address criticality are enacted.

I claimed that such political operationalization may be reflected in some EC- and US-funded projects which have aims that closely align with the recommendations put forward by the experts. This suggests that classification of criticality is a tool of valorisation including for political operationalization with distributive effects, as recipients whose interests align with the recommendations, benefit, and other parts of society, including different scientific disciplines, are silenced when the objective of the risk profiling turns to the management of risk, namely the securing of free circulation of minerals, including of the element neodymium. Arguably, the objective is that of securing mineral supply to the US and the EU.

Experts transgress the scientific boundary as they construct 'criticality', and they engage in a political discourse which begins as materials that have previously been discussed as 'key materials' are turned through classification into 'critical materials'. This criticality classification, and thus, experts through their assessments, may be, as I propose here, complicit in justifying how public funding is to be allocated (e.g. to particular types of research foci) that are seen both as offering remedies against criticality and as securing access to the minerals (i.e. by identifying new occurrences and finding new processing routes). In addition, they have drawn attention by policy-makers to the minerals, encouraging a particular focus, such as material substitution, and creating a link between the governance of resources, technological advances (including for clean energy), and national security.

In conclusion, classification enabled experts to construct the criticality of minerals, turning 'key materials' into 'critical materials' with a new set of connotations, as here examined on the case of supply risk. This bureaucratic practice of classification of criticality provides, as I argued, for a mode of securitization in line with the liberal logic of security as experts profile supply risk and recommend actions to manage this risk to secure the circulation of minerals.

The meaning of criticality is therefore rooted in the potency of this label: It reflects a valorisation, opens an avenue for operationalization, including by a discourse that is technical and expert-driven which may lead to (non-)distributive effects. It is a construct that has potency for pervading government, society and industry.

Acknowledgments

The idea for this paper emerged from the interdisciplinary workshop '*Securitization and the Boundaries of Security*' which was organized by Maya Pasgaard and Dagmar Rychnovská on May 8, 2015 at the University of Copenhagen, and during the period of the Geocenter Denmark Grant No. 04/2012. The author would like to thank the organizers of the workshop for this interdisciplinary endeavour, for carrying out the idea of this Special Issue, and for thorough rounds of commenting in internal reviews which have substantially improved this paper. For her extraordinary support with the securitization literature, the author likes to express her gratitude to Dagmar. The author would also like to thank Benjamin Faigen and Troels F.D. Nielsen for content-related discussions. The author also gratefully acknowledges the substantial contribution made by the in-depth comments provided by five anonymous reviewers, which significantly supported the revisions of this paper in two rounds. Any remaining shortcomings are the responsibility of the author alone.

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