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What makes minerals critical? Problematizing sovereignty in times of crisis

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Minerals in crisis

In February 2024, *The Economist* published an article entitled “The world needs more critical minerals. Governments are not helping”. In this article, the need for “more critical minerals” was mostly about the growing development of renewable energy technologies, which requires numerous mineral raw materials potentially in short supply, as many expert assessments have been discussing over the past few years. Quoting the figure produced by a think tank, the article opened by claiming that “if the world is to decarbonize, it will need 6,5bn tons of metals between now and 2050”. Yet the second part of the title was the real message: in this situation, what was needed was firm commitments from governments around the world, and particularly in Western countries, to support mining activities, including by making it easier for mining projects to get a license.

The *Economist*'s diagnosis identifies a problematic situation linked to the material side of energy transition and to necessary (yet missing) state interventions. The connections between the diagnosis of imminent crisis and the prescription about needed state intervention are visible more generally in current discussions about critical raw materials. What makes them “critical” is precisely the situation of crisis, whether existing or anticipated, which requires active manifestations of state sovereignty. In the *Economist* paper, as expected from a magazine known for its promotion of liberal

thought, the desired intervention of the government is about ensuring that economic actors can act. It is also about anticipating future needs in order to ensure that they will be met. The situation of crisis, here, is about the uncertain continuity of supply and the need for the state to anticipate and act on it.

The *Economist* paper proposes a definition of the crisis that makes it a joint problem of supply and government intervention. It does so in a way that re-produces an imagination of sovereignty as the ability to ensure the feasibility and conduct of economic activities (Foucault, 2004; Davies, 2017), while adding new elements to it, namely the ability to anticipate future needs and make sure that economic actors will meet them. This echoes current calls for more active state intervention in the economy to ensure that situations of crisis, in domains such as health, agriculture or the environment, are identified and acted upon. It is also vastly different from other imaginations of sovereignty that have been formulated in connection with crisis diagnosis, including in relation with minerals. As we will discuss below, the notion of “critical” minerals directly comes from military strategy, and has regularly been associated with calls for stockpiling resources and ensuring direct state control over extraction, in contrast with what the *Economist* paper envisioned as a much more indirect state intervention on the economy.

These differences show that there may well be very different answers to questions such as: what are the anticipated crises that make certain materials “critical”? What state interventions do diagnosis of crisis require? In this paper, we focus on current debates and initiatives about critical minerals to explore what makes them “critical,” or, in the language of specialists of the domain, their “criticality”. In doing so, we are interested in the connections between ways of defining situations of crisis and ways of defining state interventions. By studying these connections, we show that defining criticality is ultimately about expressing desired manifestations of sovereignty in times of crisis.

“Criticality” suggests the existence of a threat, the possibility of disruption or breakdown, and invites those in charge to act. The assessment of the criticality of minerals, or “criticality studies,” are geological, economic, and geopolitical analyses that aim to anticipate future material requirements for a national or supranational economy in order to introduce measures to secure supplies. These studies have been

conducted since the mid 20th century. They rely on expertise at the service of decision-making, whether because they are used to define targets for extraction support policies (DeYoung et al., 489-90), research priorities (Glöser et al. 2015, 44), or because they influence more generally the value that public or private actors attribute to resources (Erdmann and Graedel 2011). Accordingly, we analyze criticality studies and the knowledge and expertise they are based on to explore the kinds of state interventions they are associated with, and the kinds of crises they seek to address. After outlining a brief history of criticality studies in the next section and discussing our approach to study them, we explore below three contemporary examples in European and French contexts. In Europe, critical materials have been discussed in the context of a recent piece of regulation called the Critical Raw Materials Act. In France, national public bodies have been involved in assessing the criticality of minerals, in ways that connect with yet are vastly different from the European approach. While the European approach identifies a crisis in Europe's ability to know and act on market trends, the French cases illustrate different ways of problematizing minerals. One is the direct successor of the military history of criticality studies in that it seeks to prepare for external threats to the national economy. The other explicitly engages in future-making, and makes criticality an entry point for exploring the technical and political choices on which transition trajectories rely.

Criticality studies and the politics of the crisis

Countries involved in the First World War were concerned about the metals they needed to build their armaments. The development of research programs on this topic produced new scientific concepts such as “strategic materials” or “critical materials”. The meaning of these concepts has varied over time (DeYoung et al., 2006, Peck, 2019). In all cases, they associate industrial organization, economic value assessment and resource accessibility. Criticality studies aim to identify resources that are essential to the proper functioning of a given national economy, originally linked to military armaments needs. These military origins are exemplified by the first works on critical mineral resources in the United States. In 1922, the Army and Navy Munitions Board

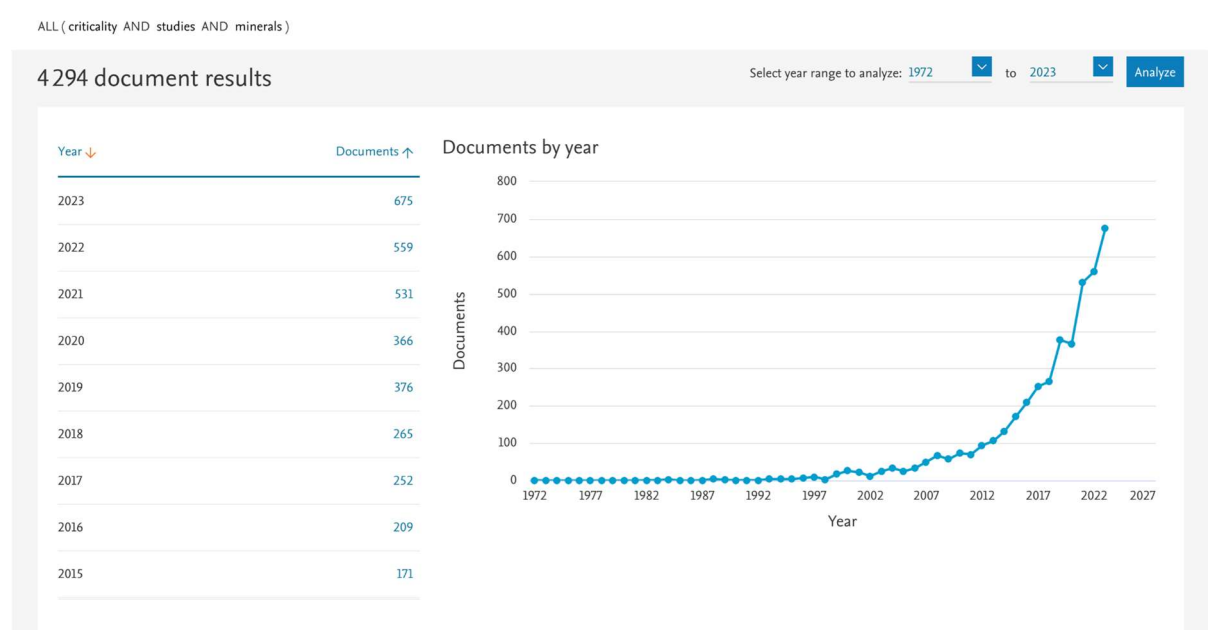
drew up a list of 14 "strategic materials" for national defense, dependent on external sources of supply, and 15 "essential critical materials," produced domestically. Later, the issue of strategic stockpiling was addressed by the 1938 Naval Appropriation Act and the 1939 Strategic Materials Act. In 1952, the "Paley report" suggested that the U.S. may not have "the material means to sustain its civilization" (Paley, 1952) if strong political measures were not taken to address these supply risks. The issue of strategic stocks was of continuous importance after the Second World War not only in the United States but also in most countries involved in the global conflicts of the period (Hache & Louvet, 2023).

Based on criticality studies, states built up stocks of metals and minerals to ensure they could maintain their supplies. By making visible the identity of resource producers and the fact that the economic functioning of markets may prove insufficient to respond to geopolitical threats, criticality studies underpinned the possibility for states to purchase and stockpile resources, and thus to anticipate future crises. In the 1970s, oil shocks played a crucial role in the design of institutions for steering strategic stock policies, beyond fossil fuels. For example, in France, they led the government to create a *Caisse Francaise des Matières Premières*. The role of this public institution was to protect French industry against possible disruptions of essential minerals supply by creating stocks on the national territory (Hache, Jeannin, 2023).

The form of state intervention based on stockpiling was profoundly reconfigured with the end of the Cold War. The military *détente* that followed served as justification for governments to sell their stockpiles. The costs of their maintenance became a public issue, amplified by the collapse of raw materials' prices during the 1990's (Hache & Louvet, 2019). Stockpiling, a sound government intervention during the Cold War, came to be interpreted as a sign of economic mismanagement.

The dual question of criticality and the role of the state was revisited in the 2000s and 2010s. In 2010, China, the world's leading exporter of rare earths, temporarily limited its exports to Japan in a period of geopolitical tensions (Verrax, 2013). This event caused what came to be known as the "Rare Earths crisis". This crisis was widely discussed across the world. It served as a justification for governments to support policy

initiatives targeting critical materials. Some of these initiatives had in fact already begun before the Sino-Japanese tensions (Boudia, 2019). As early as 2007, several initiatives targeting critical metal supplies had been launched in Western countries to counter China's hegemony in rare earth production. Reports in Japan, Europe and the US proposed lists of substances and suggested various policy interventions, which comprise stockpiles, support for technological development projects, and control of mining projects. The resurgence of political and scientific attention to critical mineral is visible in a quick bibliometric search (figure below).



Source : Scopus

The contemporary discussion of criticality is still essentially concerned with geopolitical crises. As exemplified by the war in Ukraine, military conflicts do play a crucial role in that they challenge the reliability of supply chains, forcing decision-makers to look for other lines of supply within or outside national boundaries. This investigation is increasingly complex, as the number of metals needed to manufacture many technologies (especially « high-tech ») has increased dramatically. The globalization of value chains also makes risk analysis much more difficult to carry out (Gaillaud, 2024). Unlike oil, which circulates on a much more homogeneous and organized market, critical minerals are bought and sold on many small and opaque markets, where transactions are often carried out over-the-counter.

The most important recent shift in criticality studies is undoubtedly the addition of the environmental dimension. In the context of the development of renewable energy, the growing needs for mineral resources have become pressing topics of interest, as the title of the *Economist* article with which we opened this paper shows. The growth of demands of mineral resources in connection with the development of renewable energy has re-framed international economic relations, opening a competition for the control of « green » industrial sectors. As such, criticality studies are part of a global conversation in which energy transition and national sovereignty and security are intertwined. The concept of « mineral security » has thus emerged as a diplomatic category, connecting the already existing concern about the security of supply with the possibility to develop green industries domestically in NATO countries (Vivoda, 2023). This evolution results in new imbalances. For instance, the growing demand for lithium in Western countries for the electric battery sector and its consequences in zones of extraction in South America has led scholars to speak of “green extractivism” (Jerez et al., 2021). The notion insists on the new asymmetries caused by the development of “green” industry sectors: those who benefit from these sectors are far away from those who suffer from the environmental consequences of extraction. In Europe, this has provided additional arguments for re-locating mining activities where renewable technologies are used, and/or ensuring that extractive projects follow European standards, supposedly aware of environmental and social impacts (see e.g. Pitron, 2018).

Through these recent evolutions, the criticality of mineral resources acquires another problematic dimension: how are they supposed to provide solutions to climate change if their extraction produces inevitable environmental destruction? The need to relocate mining activities in Europe has thus proved controversial, and spurred considerable debate among policy makers, representatives of the mining sector eager to launch new projects on European soil, and environmental NGOs wary of the “green” label put on extractive projects and concerned about deeper questions about sobriety or de-growth (Chailleux et al., 2022; Merlin et al., 2021).

This makes the assessment of criticality potentially problematic. All recent criticality studies cross two dimensions: economic importance and supply risk (Schrievjers et al., 2019). Yet whether economic importance means for instance ‘necessary for military objectives’ or ‘necessary for the energy transition’ is not the same thing. And even if the latter objective is chosen, then the energy transition might involve various social and technical trajectories, with vastly different consequences in terms of raw material use. Since they are meant to anticipate the crisis and thereby define what is in crisis, criticality studies also define what “resources” are, in connection to present and future objectives. Defining what is critical is also identifying what materials can be treated as resources, where these resources are, and under what technical, economic, and geographic conditions they can be valuable. Studying criticality studies as we do in this paper leads us to explore what it takes for certain raw materials to become resources worthy of collective worry. As such, this paper echoes scholarly works that have examined the regulatory, economic and material processes whereby resources come to be (Bridge, 2009; De Gregori, 1987; Merlin et al., 2021), or, to use a term recently introduced, “resourcification” processes (Hultman, 2021). We focus here on resourcification processes as empirical and analytical entry points to problematize both the crisis and the way for state actors to address it. We examine the conduct and publicization of criticality studies as sites of co-production between the ontological nature of resources and the normative appreciation about what constitutes legitimate state intervention (Jasanoff, 2004).

The methodology used in this paper is mainly qualitative. It is based on an extensive analysis of the literature produced by the subfield of criticality studies, as well as public reports produced by three different institutions that have developed their own methodologies. The discussions sparked by the adoption of the Critical Raw Material Act at the European level also allowed us to trace the controversies associated with the Commission's approach to criticality as they were raised by certain NGOs. This analysis was completed by semi-directed interviews with geologists and economists responsible for carrying out criticality studies within the three institutions we studied.

Knowing and acting on markets

The European Commission is an important actor in current debates around the criticality of mineral materials. It has been conducting criticality studies since 2011. The Commission updates its assessment every 3 years. In 2023, the European Commission published the Critical Raw Materials Act (CRMA). The main objective of this piece of legislation is to guarantee Europe's access to a secure and sustainable supply of critical raw materials. The CRMA sets targets to strengthen the resilience of the EU's critical metals supply chains: out of its total annual consumption of critical materials, the EU will have to extract 10%, transform 40%, and not depend on a third country for more than 65% of each of these materials at any given stage of transformation (by 2030). To achieve these targets, the legislation calls for the identification of strategic mining projects, both within the EU via “national geological resource exploration programmes” and in extra-European countries. The projects selected in Europe will benefit from a simplified authorization procedure, thanks to a reduction in the “administrative burden,” with shorter consultation times for local populations, limited recourse to the courts, and assistance with access to public and private funding.

The CRMA is based on a criticality study carried out by a network of geology researchers from various European universities. The rationale behind the European study is to compare minerals against each other and classify them in a list, from the most important to the least, using the two criteria of economic significance and supply risk. Both criteria are assessed using the same algorithm for all substances, based on data produced by Eurostat (the European Institute for Official Statistics) which reflects changes in resource consumption and prices over the last five years.

Copper and Nickel do not meet the CRM thresholds, but are on the CRM list as Strategic Raw Materials.

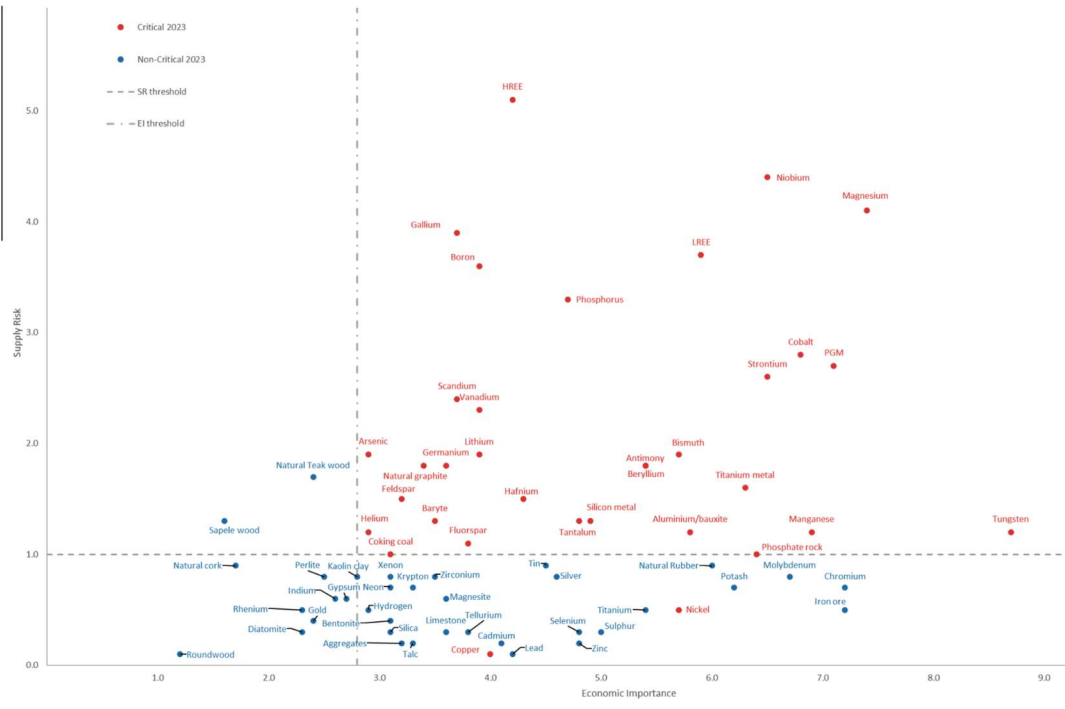


Figure A: Results of the 2023 EU criticality assessments

Figure 2: the two dimensional representation of critical minerals in the CRMA

2.1. Calculation of economic importance

I. Scope: Raw material (RM) end-use applications are assigned to the EU’s manufacturing sectors at NACE Rev.2 (2-digit level). The reference period is an average of the data from the last 5 years.

II. Formula: The following formula is used to calculate EI:

$$EI = \sum_s (A_s * Q_s) * SI_{EI}$$

where:

- *EI* is economic importance;
- *A_s* is the share of end use of a raw material in a NACE Rev. 2 2-digit level sector;
- *Q_s* is the NACE Rev. 2 2-digit level sector’s VA;
- *SI_{EI}* is the substitution index (SI) of a RM (to be used in economic importance);
- *s* denotes sector.

Figure 3: the methodology of the CRMA

This approach has two important implications.

First, the European Commission puts all substances on the same plane of quantitative economic assessment (see Figure 2). It imagines a global market of mineral resources,

where the supply and demand of each mineral can meet, and which can be described by economic assessments based on quantitative measures. Here, the market is an outside reality to be known by experts using standardized instruments and able to turn economic exchanges into scientific facts. As in many other situations in European policy circles and elsewhere, the dream is that of objectivity disentangled from political choices and expected to ensure the quality of policy decisions. As we know from analysis of other domains (Laurent, 2022), this dream is often in tension with actual practices of European expertise, which more often than not include negotiations between stakeholders. Thus, the equations proposed by the European Commission (see Figure 3) are not the only element of the CRMA story. Using them and them only led to *not* consider as critical materials such as copper or aluminum, which were key for certain industrial sectors, including defense and digital technologies. A month before the publication of the report that prepared for the future regulation, the European Commission added a new category to the assessment methodology, that of “strategic raw materials”, meant to identify substances that even though not “critical” according to the equation were nonetheless extremely important for certain industrial sectors. Environmental NGOs saw this addition as the unmistakable consequence of the intervention of major industrial companies lobbying for the support of their domains of activity, and a sign that the stated connections between the CRMA and energy transition were *not* inscribed in a meaningful environmental policy. When we met him, an expert involved in criticality assessment at the Joint Research Center (JRC) within the European Commission saw the addition of the “strategic” category as “political”, outside of the range of what was for him a “technical” intervention. These words should not be taken for granted, since the equation itself has its own politics (more on that below). Yet they signal that the public expertise on which European criticality studies rely is caught in a tension between the search for objectivity understood as originating from harmonized standards (Porter, 1995) and the usual practices of European negotiations.

A second important implication of the CRMA approach to criticality is that market analysis is based on the study of past trends, typically over the past five years, producing what an expert we met described as a “very good picture of the past”, which “settles

what demand will be”. This points to the politics of “economic importance” used to position materials on the matrix (see Figure 2). Indeed, the definition of this parameter could not include future industrial orientations (e.g. developing electric cars would require an acceleration of demands of certain minerals and metals), and this limitation then led to negotiations about what had to be added to the list of strategic minerals. As an example, this explains why a metal like copper, regularly said to be a topic of concern because of the anticipated massive growth of demand, was not considered critical according to the criteria used for these assessments. Copper is already extracted at a large scale in different parts of the world. The market for copper is not concentrated enough for the EC’s assessment to consider that it should be put on the critical minerals list.

Environmental NGOs and activists criticized the focus on existing market trends. They interpreted the hypothesis of a continuous use of minerals as contradictory with the stated objectives of the European piece of legislation, supposedly expected to contribute to environmental and energy transition, yet never questioning how the use of minerals could change. They pointed out that the idea of “twin transition” (bringing together energy and digital transitions) put forward by the Commission to justify its policy was highly questionable. In contrast, many critical voices have stressed that there could be profound incompatibilities between these two trends, and that it would be necessary to make trade-offs, if not entirely re-think transition policies in order to focus on material sobriety (EU Raw materials coalition, 2023; Observatoire des multinationales, 2023; Izoard, 2024).

This shows that the position of the European approach to critical minerals is not primarily meant to re-configure the use of minerals, question the overall politics of energy transition in Europe and possibly decide on technological choices. If there is a crisis here, it is connected to the future developments of existing market trends, and to the uncertain ability of Europe to know, accompany and possibly benefit from them. This objective - knowing and adapting to market trends - is presented as a reaction to a broader context of “transitions” in the European regulation. Yet the European matrix sees the environment only as a possible component of supply risk, considering for

instance how environmental regulations introduced by exporting countries could create tensions on existing markets.

The European diagnosis of the crisis is about the uncertain ability to know and adapt to external factors all related to the dynamics of global markets. Accordingly, the European policy intervention consists in providing enough knowledge about existing market trends of supply and demand to stimulate private initiatives and make sure that projects are launched to secure the production and supply of minerals. This is the reason why the list of minerals considered “critical” then offers a possibility to target projects considered “strategic”, and expected to benefit from priority regulatory examination. The European public intervention is about “de-risking” private interventions by identifying preferred projects and making them more attractive to investors (Gabor, 2023), and sovereignty here is tightly connected to the ability of public bodies to know markets and act for the sake of them. Sovereignty functions here on a European territory imagined as a space configured for investment by expert knowledge and regulatory action. This space extends beyond the geographic boundaries of the European Union, as various investment mechanisms are expected to incentivize projects connecting sites of extraction outside Europe and the supply of raw materials on the continent. Yet whether within the geographic boundaries of Europe or outside of it, sovereignty is based on the ability to know, react to and benefit from market trends: it is construed in explicit relation with, yet always external to the economic world.

Preparing for a national crisis

OFREMI (*Observatoire français des ressources minérales pour les filières industrielles*, French Observatory of Mineral Resources for Industrial Sectors) was created in November 2022 following a government report on securing the supply of mineral raw materials, written by Philippe Varin, a senior civil servant and former CEO of the Peugeot automotive company. Varin advised the government to set up an authority to improve the control of value chains for critical minerals, in the context of policy initiatives meant to “re-industrialize France”. The French Ministry of Industry

responded to this request by creating OFREMI, an observatory attached to BRGM, the national geological survey in charge of assessing the French underground resources and studying the potential for extractive projects on the French territory. OFREMI brought together geologists and economists specializing in critical materials from BRGM. Their task was to define a new methodology for assessing criticality, in order to standardize existing initiatives in French research institutions, and to consider how these studies could contribute to new industrial policies.

OFREMI's studies assess the criticality of minerals according to their economic importance for the French national economy and their supply risks. A first difference with the European Commission's approach to criticality is linked to the way in which the designers of the French methodology define the role of scientific expertise. OFREMI does not consider the criticality of resources by comparing them with each other on the basis of critical or non-critical thresholds quantified through a standardized equation (as in Figure 3). Criticality is assessed on the basis of idiosyncratic scores from 1 to 5. When we met him, the leader of OFREMI's studies explicitly compared his approach to that of the Commission:

"At the European level, they choose thresholds for each of the two dimensions, and the substances that are in the criticality zone are going to be part of the criticality list. And those that are not will not be critical. We don't set a threshold, so it's up to each individual expert to see whether there are more or less critical substances, and we put a value between "very weak" and "very strong" for each of the dimensions, giving a score from 1 to 5, but after that, we don't draw up a list. So we don't have to talk about critical or non-critical substances, we just talk about the criticality of the substances".

In European policy circles, the assessment of criticality is based on mathematical formulas that can be applied in the same way to all resources. By contrast, OFREMI mobilizes different geological experts for each substance ("individual experts" in the quote above) in order to produce a "criticality score" (see example in Figure 4).

CRITICITE DU DYSPROSIUM

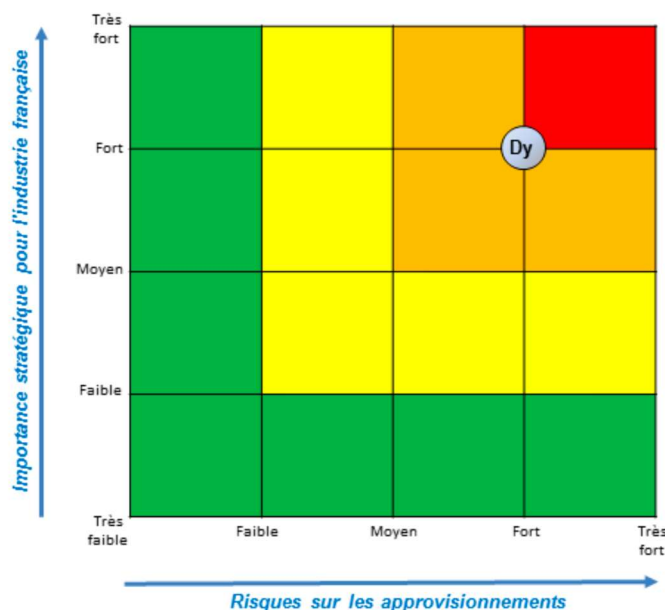


Figure 4: A case of criticality study for a mineral (dysprosium)

Experts are selected at the discretion of OFREMI's management. In most cases, they are BRGM geologists who have been working on a resource for many years. OFREMI can also call on the expertise of other French scientific partner organizations (such as IFPEN¹ or CEA², for example). Once selected, the experts in charge of analyzing the criticality of a resource assess each criterion of the study according to their understanding of the market dynamics of the resource under study. To assess this dynamic, experts draw on their personal experience, carry out a press review, draw on scientific literature or reports from other institutions. They may also contact manufacturers on behalf of OFREMI to request sensitive or confidential data.

In other words, OFREMI sees scientific objectivity as not depending on standardized expertise framed by the use of a mathematized protocol. Rather, they rely on the embodied skills of professional experts able to draw on their own knowledge while drawing on OFREMI's networks of public and private contacts deemed competent to

¹ *Institut Français du Pétrole Energies Nouvelles* (French Institute of petroleum and new energies)

² *Commissariat à l'Énergie atomique* (French Alternative Energies and Atomic Energy Commission)

anticipate problems on targeted markets. This organization was deliberate. Relying on professional experts was in OFREMI's view a way of producing knowledge about the multiplicity of markets for critical minerals. Contrary to the European imagination of a global market of minerals described through a single equation, OFREMI seeks to explore the specific dynamics of each mineral, and mobilize only dedicated experts who can precisely identify which part of the value chain of each mineral is truly "critical". For example, if supply risks originate from the concentration of refining capacity in a specific country rather than from geological scarcity, then OFREMI experts consider that this difference needs to be clarified. The people in charge of OFREMI we met considered this plural approach to criticality as a way of getting "the right political messages" across to decision-makers, and avoiding the tension between a standardized description of criticality and the *ad hoc* addition of "strategic" substances.

These "political messages" relate above all to the anticipation of supply crises with a 5-year time horizon. The OFREMI people we met drew parallels with what was referred to in the French media as the "mask crisis" at the time of the Covid-19 pandemic. During the first epidemic peak in France in March 2020, the Ministry of Health had to manage a shortage of surgical masks due to a decision a few months earlier not to replenish mask stocks for budgetary reasons. Experts and media analysts saw this episode as an illustration of the failure of the French state to anticipate security and safety crisis and secure the supply of essential raw materials within national boundaries. At OFREMI, this episode was a reference point and a justification for adding a new dimension to criticality alongside the two criteria of economic importance and supply risks. This new dimension was about "the ability to cope with a supply failure", assessed at the level of the French territory by experts for each substance.

The style of criticality studies proposed by OFREMI is associated with a form of public intervention that does not rely primarily on action on and by the markets (as in the European case), but on crisis preparedness (Collier, 2008). Here, crisis preparedness includes a permanent surveillance of the global markets and of national strategies about critical minerals, designed to inform and advise French industries about supply management. Preparedness also comprises stress tests for companies and public

administrations, currently underway to test different supply disruption scenarios. These instruments aim to prepare industrial actors for possible shocks, by suggesting risk mitigation strategies in the short and medium term. These strategies may include, for example, the diversification of supply sources, by advising industrial companies to buy shares in new mining projects. Echoing the military origin of criticality studies and their association with stockpiling, our interlocutors also mentioned that the distribution of storage costs between private and public actors, and the degree of public communication about the existence of stocks of critical materials were topics of discussion at OFREMI and in government circles.

Whether preparedness uses market surveillance, stress tests or stockpiling, it engages the positioning of public and private actors and the relations between them. Producers of substances considered critical might use this characteristic when negotiating regulatory or financial support with public authorities. Users, on the other hand, are likely to suffer constraints if the critical nature of a substance results in an incentive (or even a regulatory request) to substitute it with an alternative.

Whatever the eventual decisions that the OFREMI criticality studies will lead to, the crisis it diagnoses is about national security and the upcoming threats it faces because of the potential disruption of supply chains that cross national boundaries. In response, the appropriate government intervention is about developing what OFREMI calls “mineral intelligence” (just like companies speak of competitive intelligence). Mineral intelligence points to a way of gathering and managing economic information for preparing national actors to withstand external shocks. These criticality studies do produce knowledge about economic trends; yet they do so in a way that vastly differs from the production of knowledge about the global market envisioned by the European Commission’s algorithm. Here, expertise about minerals is embodied in professional experts, produced by a public institution tied to direct state interventions meant to prepare for external threats to the continuous supply of necessary minerals within national boundaries. The crisis is national and state intervention about preparing to what threatens the national economy.

Debating energy planning

The criticality of mineral materials is often discussed in relation with the material needs of energy transitions, as exemplified by the recurrent discussion about lithium supply for electric vehicles batteries. In recent years, companies and public bodies in charge of designing and implementing transition policies have started to tackle the criticality of raw materials in their own ways. One striking example is RTE (*Réseau de Transport d'Électricité*, Electricity Transportation Network), the operator of the French electricity transmission system. This state-owned company is in charge of electricity infrastructures in France. Its task is to ensure that electricity production continually matches consumption. RTE has been invoking this mission to emphasize its pivotal part in the energy transition, stressing that the share of electricity in the total energy consumption (25% in 2020) is expected to reach 55% in 2050 according to the official national decarbonation strategy (RTE 2021, 47). RTE's position as an intermediary between electricity production and consumption has led the company to formulate recommendations for energy planning, in public reports that outline different scenarios and compare their benefits and drawbacks. In 2021, the "Energy Futures for 2050" report (*Futurs énergétiques 2050*) was the first to systematically address the implications of different scenarios in terms of raw materials consumption. For the first time, RTE presented its own understanding of the criticality of minerals.

This report discussed different possible futures for the national economy, including a "reference scenario," a "sobriety scenario," and a "deep reindustrialization of France" scenario. The 39-page section of the report dedicated to raw materials consumption primarily connects the criticality of minerals with their uses, in relation to each scenario. This is made clear in the table listing raw materials and summarizing their technical uses (see figure 5)

Figure 12.30 Technologies et ressources minérales étudiées

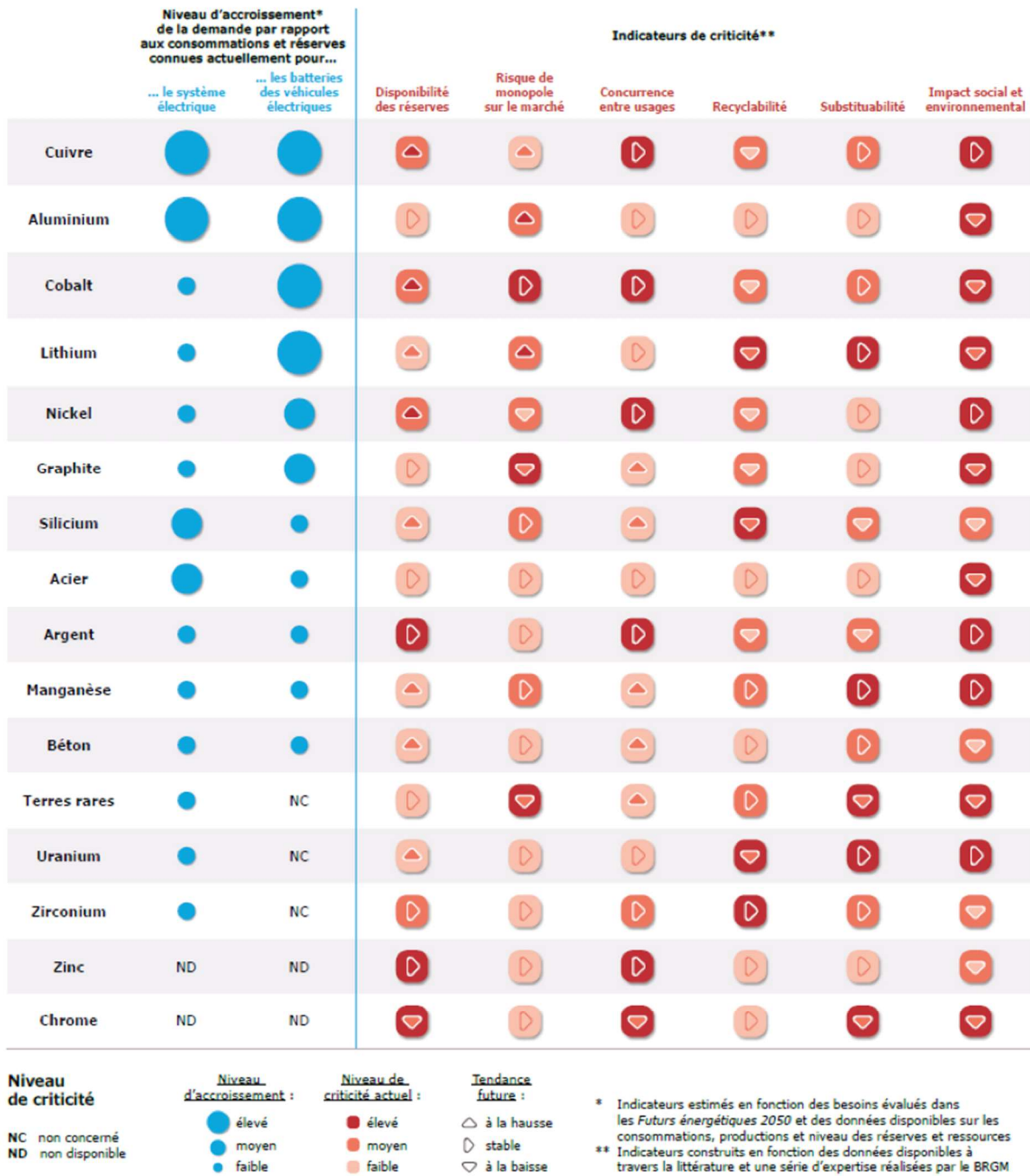
	Batteries	Réseau	Nucléaire	Photovoltaïque	Éolien terrestre	Éolien en mer	Hydraulique	CCG Gaz	Charbon
Aluminium	●	●	●	●	●	●	●	●	●
Cuivre	●	●	●	●	●	●	●	●	●
Acier	●	●	●	●	●	●	●	●	●
Béton	●	●	●	●	●	●	●	●	●
Terres rares						●			
Argent	●			●					
Silicium		○		●					
Uranium			●						
Zirconium			●						
Graphite	●			●					
Lithium	●								
Cobalt	●								
Manganèse	●	○	○	○	○	○	○	○	○
Nickel	●	○	○	○	○	○	○	○	○
Chrome	○	○	○	○	○	○	○	○	○
Zinc	○	○	○	○	○	○	○	○	○

● Ressource mobilisée dans la structure ou pour le combustible ○ Ressource mobilisée dans des alliages (non quantifiable)

Figure 5: list of minerals and possible uses in RTE *Energy Futures* report

As part of the assessment of concurrent scenarios, RTE’s criticality assessment displays a number of consequences of the reliance on mineral raw materials. These consequences are presented in what the report terms its “criticality matrix,” a second table that summarizes the expected growth in demand (for the electric grid in general and for car batteries) and the level and expected variations of 6 “criticality indicators” (see figure 6).

Figure 12.31 Enjeux de criticité des ressources clés en 2019 et les tendances à venir vues d'aujourd'hui au regard des besoins dans les *Futurs Énergétiques 2050*



Clé de lecture : le niveau de risque d'approvisionnement du cuivre vis-à-vis des réserves actuelles est moyen et risque de devenir élevé dans les prochaines années/décennies ; ses capacités de recyclage sont moyennes aujourd'hui et pourraient s'améliorer dans le futur, tandis que l'exploitation minière du cuivre a un impact environnemental et social (pour les populations riveraines) élevé et risque de le rester dans les années à venir. De plus, dans les *Futurs énergétiques 2050*, les besoins de cuivre sont élevés par rapport au niveau de consommation actuelle en France (besoins représentant plus de 20 % de la consommation actuelle totale de cuivre, voir partie 12.3.5.1).

Figure 6: Criticality matrix in RTE *Energy Futures* report

The two criteria used in the report to define criticality (“availability of the substance,” “economic importance,” p. 687) match the general framework we encountered in the European Commission and at OFREMI. Yet this table does not resemble more classical,

bidimensional criticality matrices (as in Figure 1 and Figure 4). Contrary to those we encountered at the European Commission, it limits the possibility to compare in quantitative terms the overall level of criticality of different minerals, in several ways. First, quantification itself is limited, with only three levels for each indicator, rather than numbers. Second, the time dimension makes the ranking more complex. Consider for instance a situation in which one tries to compare the criticality of copper (first row) and nickel (fifth row) from the point of view of monopoly risk (second indicator). Then, it is unclear whether nickel or copper is more critical. Nickel could be considered more critical as its risk is rated “medium” rather than “low”. But copper could also be more critical because its risk is expected to rise in the future (as indicated by the arrow pointing upwards), while that of nickel is expected to shrink. Third, and perhaps most importantly, no weighing of the different indicators exists, and there is no possibility to produce a single, aggregated criticality index. This is an important characteristic of RTE’s approach to criticality, especially as certain indicators take very different values from one mineral to another, while others vary more subtly. Social and environmental impacts (last column), in particular, make comparisons difficult as their level is rated highly for 12 in 16 materials considered, this being justified as follows: “the social and environmental impact of the exploitation of a resource is by nature non-negligible, all the more so in the case of mining exploitation” (p. 964). Ultimately, using this matrix to compare the criticality of two or more materials forces the reader to be explicit about the indicators they favor in their assessment.

RTE’s version of criticality frames technical and economic assessments as a multi-dimensional processes open for collective discussion. Criticality is qualified as being *à géométrie variable* (p. 687, i.e. “subject to variation”), due to the variety of factors at play. RTE’s criticality matrix is not intended to provide a quantified and would-be objective description of existing market trends (as in the European CRMA) or a well-informed evaluation for anticipating crises of supply (as in the French OFREMI), which an aggregate index would summarize. Rather, it serves as a starting point to discuss which indicators are the most relevant for each set of materials in relation to their uses. In RTE’s report, the matrix is followed by 14 subsections with titles such as:

“Rare earth elements, often mentioned in the debate, are in practice not problematic in the first order from the point of view of the electric system” (p. 691);

“Manganese: moderate supply risks, but important environmental and social consequences” (p. 703);

“Copper: a critical metal, consumed in the electric sector as well as numerous other sectors, with a middle-term risk of supply tensions” (p. 706);

“Chrome and zinc: needs that are difficult to quantify, but limited issues due to very good recycling performances” (p. 710).

In other words, RTE ultimately compares the criticality of materials not through numeric quantification but through differentiated qualification requiring plural sources of expertise. This approach is in line with the operator’s broader effort to discuss the plurality of consequences of different possible energy futures. RTE’s report insists on “transparency” to justify a consultation process that gathered feedback from 160 institutional stakeholders (research and expertise organisms, private corporations, public administrations, non-governmental organizations) as well as individual responses to a public consultation. The consideration of material flows in different scenarios translates into a form of objectivity that relies on different fields of expertise—geology and economy, but also engineering and social sciences, etc.—while discussing their relative roles by directing attention to different indicators for each set of materials. As its primary concern lies with the security of energy supply rather than raw materials, RTE proposes an approach to criticality that makes it a topic for collective discussion rather than an external reality to be assessed. This means that what is critical in certain scenarios will not be for others, and that, ultimately, the crisis is not an exogenous event to which one needs to adapt, but an impetus to craft desirable futures in collective ways. The crisis is not a specific event coming from external threats to which a given country should prepare, but a global ecological crisis in which we are all already living. Therefore, it is not connected to the availability of minerals on existing markets, as if availability could be assessed independently from minerals’ uses. Rather, the crisis is defined in relation to the contribution of potential technologies to broader energy choices. Here, public interventions are about general and collective objectives

(such as: providing electricity for all), and crafting channels of representation to meet them. It is therefore associated with a reflection on the fairness that each energy trajectory allows, who is made possible by a broad public consultation informed and led by engineers. On complex topics such as energy choices and material resources, this requires attempting new formats of exploration of potential futures.

Criticality and critique

The three examples we discussed offer striking contrasts between different ways of conducting criticality studies. They are based on different kinds of expert knowledge, whether standardized algorithms in the European case, qualitative assessments voiced by individual experts at OFREMI, or the collective evaluation of material and energy flows in each of RTE's scenarios. Importantly, the three initiatives do not define criticality in the same way. While the European Commission envisions a unified global market of resources, the French experts work on distinct minerals with specific technical, economic and geostrategic characteristics. At RTE, the criticality of minerals depends on broader production, distribution and consumption choices, as well as social, political and environmental constraints: criticality is not an external quality that experts can assess, but a topic for collective discussions related to desirable energy futures. These differences are associated with different expectations about the role of the state and ultimately about the nature of sovereignty in times of crisis. The European CRMA sees the role of European public bodies as de-risking private investments, in easing the distribution of licenses for projects deemed "strategic", providing collateral funds for attracting investment, and partnering with extra-European actors. By contrast, OFREMI re-produces what was central in military reasoning about raw materials. OFREMI sees the role of state intervention as the ability to manage potential disruptions of supply chains by creating a surveillance and preparation system with the collaboration of industrial actors. Eventually, RTE organizes the collective exploration of energy futures and their material dependencies, at the service of an overall objective of ensuring the supply of electricity across the country and for the sake of a vision of sovereignty originating from the production of the general interest.

These differences in defining the problem of criticality and the ways of addressing it point to differences in understanding what is in crisis. All three examples concur in identifying issues and difficulties regarding the ability to access needed minerals in energy transition contexts. Yet these issues and difficulties are considerably different because what the “needs” are, whose needs are considered and for the sake of what future developments are not consensual matters. If European public bodies diagnose a potential crisis of supply, it is a crisis related to Europe’s ability to know and act on markets understood as external to political debates. The crisis of supply, for OFREMI experts, is a crisis of the ability of the French state to mobilize resources if external geopolitical shocks disrupt material flows across national boundaries. RTE proposes a radically different version of the crisis: not entirely caused by external factors any more, it becomes a topic for collective discussion about desirable futures, and their associated material, economic and social constraints.

Analyzing criticality studies as sites of joint problematization of the crisis and state interventions meant to address it as we did in this paper displaces the critical dimension. What becomes critical is now also the outcome of scholarly exploration. The comparison between different versions of criticality then offers conceptual and political space for re-framing what the crisis is about. It invites us to re-narrate the existing diagnosis of the crisis of raw materials. The last example we discussed is particularly useful for that matter. It suggests that rather than a crisis of knowledge of and adaptation to market trends (as diagnosed in European policy circles) or a crisis of national security (as construed at OFREMI), the crisis might well be about the ability of democratic institutions to discuss what energy transition should be about and whom it should benefit.

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