Critical Thinking about Critical Minerals

Assessing risks related to resource security

Bram Buijs and Henrike Sievers[1]

November 2011

As a consequence of the tight conditions overshadowing today's resource markets, concerns over access to raw materials have been rising again in recent years. This paper places the debate on resource security in an historical context by pointing out the parallels between current concerns and earlier periods. Furthermore, it discusses a number of recent and historical criticality studies that have been used in analysing potential problems relating to the access to raw materials and the identification of 'critical minerals'. It argues that these studies have serious limitations regarding their use in assessing major future risks. Although these (methodological) limitations are usually acknowledged in the studies, their results – prominently a list of critical raw materials – are often misinterpreted and misrepresented, opening the door to overreaction. It is important to be aware of the shortcomings of these critical minerals studies, including that they:

- Lack predictive power beyond the short term,
- Tend to overstate the economic impact of a possible supply disruption of 'critical' minerals,
- Fail to distinguish between short-term and long-term problems,
- Insufficiently take into account the diversity and particular characteristics of the resource markets that are analysed,
- Focus exclusively on risks related to the mining and export of raw materials, but disregard the larger production chain (e.g. refining, transport, and trade in semi-products).

Instead of giving a false appearance of certainty by pinpointing which specific raw materials might lead to economic or political tension, we argue that an analysis of more 'generic' mechanisms and potential risks in the resource sector can be more useful. Such an approach can then provide a basis from which to analyse future risks in the resource sector and identify suitable policy responses.

---

[1] This briefing paper has been based upon research undertaken in the context of the EU FP7 POLINARES project (www.polinares.eu). The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement n° 244516.
For questions or matters of citation, the authors can be contacted at bbuijs@clingendael.nl and henrike.sievers@bgr.de. Bram Buijs is researcher at the Clingendael International Energy Programme, and Henrike Sievers is researcher at the Bundesanstalt für Geowissenschaften und Rohstoffe (the German Geological Survey).

Historical background and introduction to resource criticality studies

"The recent tight supply situation for energy, food and many raw materials has also prompted a more general concern—that we may be passing from an era of abundant supplies into one of constant shortages."

July 1974, US Government (Nixon Administration)
Critical Imported Materials: Study of Ad Hoc Group Established by NSSM 197/CIEPSM 33[2]

In recent times, tensions have been running high concerning possible scarcities of natural resources[3]. It is important to realise that such concerns are a recurring theme throughout history, resurfacing again and again, primarily in response to tight market conditions and price increases.

The fundamental cause for this recurrence lies largely in the characteristics of the resource extraction industry. The high investment costs and long lead times for new supplies to come on stream – typical of most of the energy and mineral mining sector – means that there is a slow and inelastic response to changes in demand and price, which often leads to a pattern of 'hog cycles' of market slumps and price spikes.

An analysis of the history of the energy and mineral-mining sectors illustrates such market cycles and the corresponding political cycles of attention, concern and tension around the topic of resource availability. Such cycles also cause shifts in the balance of bargaining power between consumer and producer countries, as well as between host governments and companies involved in resource extraction, denoted by the *obsolescing bargain* principle[4]. Related to this, industry cycles also go quite far in explaining the periodic resurgence of resource nationalism, as increasing monetary value of extracted resources inherently leads to a greater politicisation of control over them.

In fact, the essential concerns have mostly remained the same in the past decades, focusing on the (potential) impact of accidental or intentional supply disruptions to the economy, as far as its dependency upon certain imported materials is concerned.

Energy resources have always attracted a specific strategic interest, due to their very clear and huge impact on the functioning of the general economy, high value and the lack of substitutability in even the medium or longer term. Specifically, oil and gas have been treated with much concern, due to

---

[2] National Security Study Memorandums (NSSM), *Critical Imported Materials: Study of Ad Hoc Group Established by NSSM 197/CIEPSM 33,* US Government (Nixon Administration), 1974. Available at the US Bureau of Public Affairs, Office of the Historian. "Foreign Relations of the United States, 1969–1976, Volume XXXI, Foreign Economic Policy, 1973–1976". Available online at: http://history.state.gov/historicaldocuments/frus1969-76v31.

[3] See, for instance: *Euractiv, "*Raw materials: Towards a Global Resource War?", 3 March 2011. Available online at: http://www.euractiv.com/en/specialreport-rawmaterials/raw-materials-global-resource-war-news-502704 (accessed on 3 March 2011).

[4] See, for instance, the working papers published as part of the EU Polinares project, Work Package 1: David Humphreys, "Minerals: Industry History and Fault Lines of Conflict", September 2010, and Paul Stevens, "The History of Oil", September 2010. Both are available online at: http://www.polinares.eu/publications_deliverables_d1_1.html.

the (perceived) limitations of expanding and diversifying supplies, whereas coal and uranium have led to fewer political tensions due to a wider resource base and a diversified field of producers[5].

Regarding mineral resources, concerns about specific raw materials have fluctuated significantly with market circumstances. Furthermore, the sets of raw materials thought by certain countries to be critical have changed over time. The following examples serve as an illustration:

- In the mid 1970s the *Critical Imported Materials: Study of Ad Hoc Group Established by NSSM 197 / CIEPSM 33* argued that the following materials should be considered critical for the US: bauxite, chromium and platinum[6].
- The report *Strategic Critical Nonfuel Minerals: Problems and Policy Alternatives* (1983) by the US Congressional Budget Office identified: chromium, cobalt, manganese and platinum-group metals (PGMs)[7].
- In 1975 the *Commission of the European Community* published a communication on the raw materials supply of the Community[8]. To secure this supply, the possible solutions proposed were: long-term treaties of companies with producers, stockpiling, trade agreements, support of exploration (inside and outside Europe), increasing knowledge/research and creating appropriate structures within the EC. The following materials were identified as raw materials of concern: tungsten, manganese, chromium, phosphate and platinum[9].

An interesting observation is that although these historical criticality studies used basically the same approach as recent studies, the resulting selection of 'critical minerals' is different from ones currently identified[10].

A second important observation is that not only are the fundamental concerns which are discussed in these historic studies the same as those today, but, to a large extent, so are the subsequent analysis and proposed solutions. The communication on the security of the Community's raw materials supply published by the European Commission in 1975 is an excellent example. It states that although a geological scarcity is not foreseeable, the supply of raw materials is of high importance for the future. Risks for supply bottlenecks were seen in Europe's import dependence, the concentration of production in unstable countries, the nationalisation of mining companies and the increasing tendency to process raw materials in the producer countries. Several measures were proposed to counteract possible supply shortages: stockpiling of raw materials, long-term supply contracts and the exploitation of European resources. Recycling, substitution, efficiency, longer product lifetime and supporting research activities were mentioned as supporting measures.

---

[5] In the case of uranium, concerns have focused on enrichment and non-proliferation issues, not on mining and trade.

[6] National Security Study Memorandums (NSSM), *Critical Imported Materials: Study of Ad Hoc Group Established by NSSM 197/CIEPSM 33,* US Government (Nixon Administration), 1974. Available at the US Bureau of Public Affairs, Office of the Historian. "Foreign Relations of the United States, 1969–1976, Volume XXXI, Foreign Economic Policy, 1973–1976". Available online at: http://history.state.gov/historicaldocuments/frus1969-76v31.

[7] US Congressional Budget Office, *Strategic Critical Nonfuel Minerals: Problems and Policy Alternatives*, 1983. Available online at: http://www.cbo.gov/ftpdocs/50xx/doc5043/doc15-Entire.pdf (accessed 16 September 2010).

[8] Communication by the Commission of the European Community, Bulletin of the European Communities, 1/75, 1975.

[9] With regard to metals used for steel alloys, some observed: "Future development is expected to increase even the import dependence of few large producing countries in the Third World, thus increasing the risk of short-term availability bottlenecks, shortcomings in deliveries and cartelizations in view of a sharply rising demand of alloy metals and a shortage of Europe's own production." J. Feldmann, *Journal of Materials Technology*, Vol. 12, 1975.

[10] This shows that criticality studies can only provide a snapshot of a dynamic system with little predicative power. We will discuss this issue (and criticality study methodologies) in the next section.

The Commission document furthermore states that the problem exceeds the national frame of the member states and that therefore an attempt should be made to find a common solution for all European states. It suggests creating a body within the Community which would pool knowledge and information on raw materials. Furthermore, it emphasises that only with a systematically organised, close collaboration of all relevant disciplines can the knowledge base needed to shape a European resource policy be created[11]. Again, the similarities with recent policy statements are striking.

Since contemporary concerns show such strong similarities with earlier periods, it is worthwhile to briefly analyse the historical development of the thinking about critical minerals.

An explanation of the change in the political attention to resource policy between the 1970s and late 2000s is given in various accounts[12]. First, the end of the Cold War changed the political perception of resource security in the 1980s and 1990s. After the Cold War, with the hope of more markets opening, concerns about the security of resource supply became less urgent. The notion that a free, globalised market would provide sufficient raw materials and that an active resource policy was no longer necessary, prevailed. Instead of supply security, discussions on environmental and social aspects gained attention and were included in laws.

During the Cold War, regions were divided into blocs (spheres of influence). Inter-regional raw material flows were restricted by the political conditions, and as such there was a tendency towards raw materials independence within these blocs. After the Cold War ended, inter-regional trade flows increased and a true globalisation of the raw materials supply took place[13]. The changes also led to the end of local price regimes, which were replaced by the trade of metallic raw materials at the London Metal Exchange. States increasingly withdrew their activities from the resource sector, and a number of former state companies were privatised in the '90s[14]. Exploration activities of the mining companies, for a long time focused on Australia, Canada and the US, were now directed to other regions, especially South America. For new energy investments, Russia and Central Asia were favoured destinations.

Another major shift that began at this time was the growth of China into a key raw materials consuming and producing country. Some raw materials formerly produced in Western industrialised countries were now produced in China (including, for instance, rare earths). Since the beginning of the new millennium China's demand for resources has increased sharply, as much manufacturing activity has shifted to China. Demand for internationally traded iron ore, for instance, grew at about 2% per year between 1980 and 2000. However, growth accelerated to an average annual increase of approximately 9% between 2000 and 2010.[15]

---

[11] Also at this time, the first Lomé Treaty was signed (1976) which aimed to establish a form of producer-consumer dialogue between the European Community and a group of developing countries from Africa, Caribbean and the Pacific (ACP), by means of the Stabex, Minex and Sysmin compensatory finance systems that aimed to help stabilise export earnings for these countries in the face of price volatility of minerals and other commodities.

[12] See, for instance: David Humphreys, "Whatever Happened to Security of Supply? Minerals Policy in the Post-Cold War World", *Resources Policy,* Vol. 21, No. 2, pp. 91-97. 1995; David Humphreys, "Minerals: Industry History and Fault Lines of Conflict", September 2010, Briefing Paper part of Work Package 1 of the POLINARES project. Available online at: http://www.polinares.eu/publications_deliverables_d1_1.html.

[13] David Humphreys, "Whatever Happened to Security of Supply? Minerals Policy in the Post-Cold War World", *Resources Policy*, Vol. 21, No. 2, 1995, pp. 91-97.

[14] E.g. CVRD in Brazil, Cerro Verde and Tintaya in Peru.

[15] David Humphreys, POLINARES internal documents and private communication.

The increase in demand for nickel and copper from 2000 to 2008 was driven nearly entirely by China. China also accounted for about two-thirds of the global increase in demand for aluminium and steel during that period[16]. In this new millennium China has become the biggest raw materials consumer (see Figure 1). As another example, in 1997 China consumed about 10% of the global iron ore and zinc production. Ten years later, in 2007, the country's consumption had increased to about 45% of the global iron ore production and about 40% of the zinc production. It is obviously a key imperative for China to supply its domestic industries with the resources it needs, and Chinese companies have stepped up their global investment in mining projects. These activities are supported by the Chinese government and are partly undertaken by state-controlled companies.

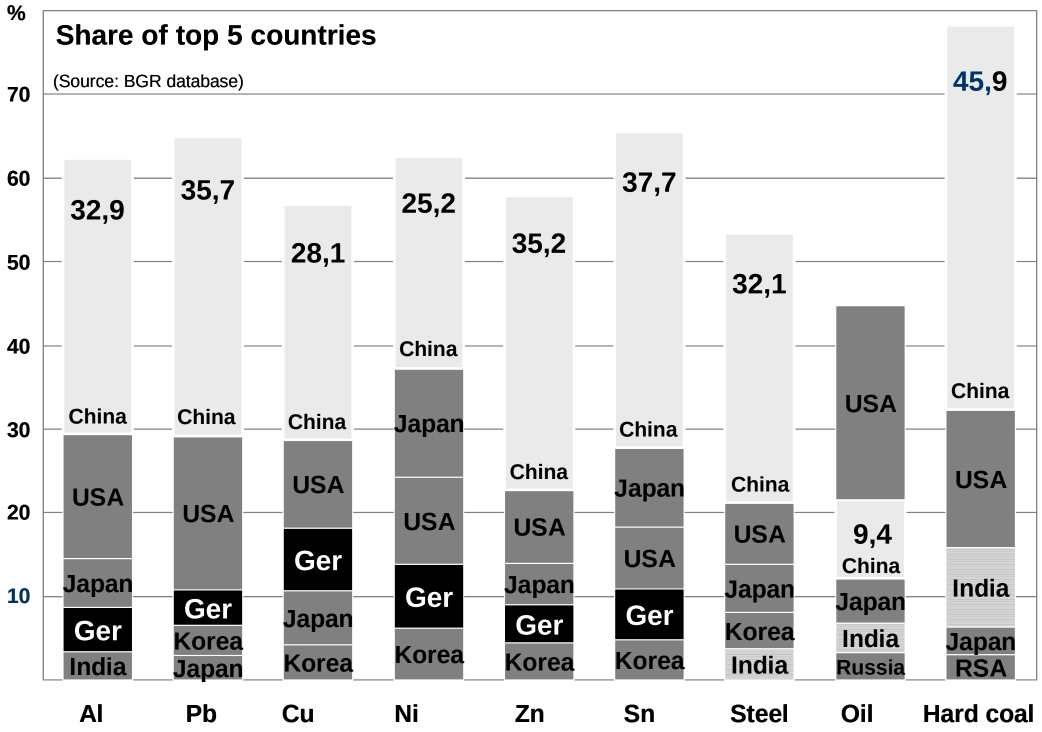

Figure 1: Metal consumption of the five leading nations in 2008. Source: BGR database, 2011.

China's increasing demand for raw materials, coupled with the country's protectionist measures and steps toward securing access to foreign resources, has recently evoked concerns in the EU and other industrialised countries about the security of their own resource supplies. The EU and its member states are paying attention to the topic through studies, resource strategies and programmes which have the goal of increasing resource efficiency. In 2010 the European Commission published a report on critical raw materials, which classifies 14 materials as critical[17]. Furthermore, in 2011 the Commission published a communication on raw materials that states: "The EU will actively pursue a 'raw materials diplomacy' with a view to securing access to raw materials, in particular the critical

---

[16] David Humphreys, "The Great Metals Boom: A Retrospective", *Resources Policy*, Volume 35, No. 1. ISSN 0301-4207.

[17] European Commission, *Critical raw materials for the EU*, Report of the Ad-hoc Working Group on defining critical raw materials, 30 July 2010. Available online at: http://ec.europa.eu/enterprise/policies/raw-materials/files/docs/report-b_en.pdf.

ones, through strategic partnerships and policy dialogues”.[18] Other countries, such as Japan and South Korea, are also looking for ways to address their resource dependence and support their industries in order to secure their access to raw materials sources abroad.

State engagement in the resource sector, set against the background of the political conditions of the Cold War and the concern about supply security in the ‘70s, was followed by a company-dominated, free, globalised market in the ‘90s. Yet at the end of the 2000s the pendulum seems to be swinging back towards increasing state engagement, at least in the discussions about raw material needs and supply. This might lead to an increasing state control or influence over the resource sector. The development of the cyclical periods of state involvement in and withdrawal from the resource sector was also described in detail in Work Package 1 of the EU FP7 POLINARES project, described as the ‘regime approach’ (see Figure 2).

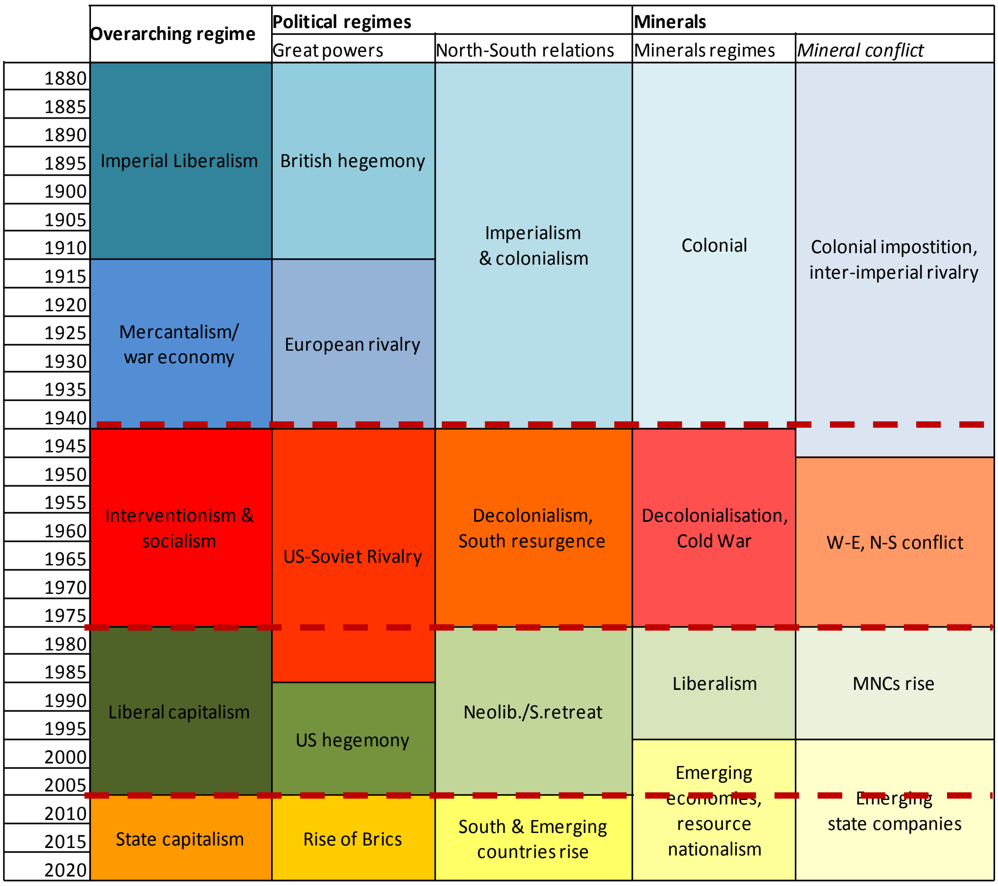

Figure 2: Regimes relevant to the resource sector and overarching regimes according to Polinares WP1 (POLINARES, 2010).[19]

[18] Communication by the European Commission, “Tackling the Challenges in the Commodity Markets and in Raw Materials”. COM(2011) 25 final, Brussels, 2 February 2011.

[19] POLINARES, “Framework for understanding the sources of conflict and tension”, Work Package 1, internal project document, April 2010. For POLINARES related research and document, see: www.polinares.eu.

Criticality studies and their methodology

In recent years there has been an increasing trend towards trying to quantify the supply risks and the (economic) impact of supply disruptions of certain materials. This has led to the use of indicators, such as the Human Development Index or the World Bank's Worldwide Governance Indicators[20], to measure the political stability of raw-material-producing countries and the potential for supply disruptions. To identify the economic impact of a supply disruption of certain minerals estimates are made, for instance by calculating the value of the products or overall industry output dependent upon a certain material and adjusting for the potential of substitution and increased resource efficiency.[21]

We mention here a few recent reports and sets of 'critical minerals' identified in the reports, also describing the respective criteria and methodology by which these minerals were selected:

- *Minerals, Critical Minerals, and the US Economy* (2008):
  Minerals identified as critical: indium, manganese, niobium, platinum-group metals, and rare earths.
  Methodology: these 4 most critical minerals are shortlisted out of a selection of 11 minerals (including also: copper, gallium, indium, lithium, tantalum, titanium and vanadium), on the basis of two criteria: the impact of supply restriction (based on the fundamental importance of the material in certain industry sectors and the difficulty, expense and time of finding a suitable substitute) and the supply risk (based on strong import dependency on a dominant supplier).
- *Material Security. Ensuring Resource Availability for the UK Economy* (2008)[22]:
  Minerals identified as critical: gold, rhodium, platinum, strontium, silver, antimony and tin.
  Methodology: selected from 69 'insecure materials' – mainly metals – on the basis of 8 criteria involving global consumption levels, lack of substitutability, global warming potential (due to extraction), total material requirement (indicating environmental impact), scarcity (physical/absolute), monopoly supply, political instability (of major producers) and climate change vulnerability (of producer regions).
- *Critical Materials Strategy* (2010) by the US Department of Energy[23]:
  Minerals identified as critical: five rare earth elements (dysprosium, neodymium, terbium, europium and yttrium) and indium.
  Methodology: selected from 14 minerals on the basis of two criteria: supply risk and importance to clean energy technologies.

[20] World Bank, *Worldwide Governance Indicators*. See: http://info.worldbank.org/governance/wgi/index.asp.

[21] This is the case for the *Critical raw materials for the EU* study from 2010 by the European Commission. For other studies the methodology for calculating the economic impact is generally not transparent, though the factors considered are similar.

[22] Oakdene Hollins*, Material Security: Ensuring Resource Availability for the UK Economy*, March 2008.

[23] US Department of Energy, *Critical Materials Strategy*, December 2010. Available online at: http://cr.aiag.org/files/criticalmaterialsstrategy.pdf.

- *Critical Raw Materials for the EU* (2010) by the Ad-hoc Working Group on Defining Critical Raw Materials and European Commission[24]:
  Minerals identified as critical: antimony, beryllium, cobalt, fluorspar, gallium, germanium, graphite, indium, magnesium, niobium, platinum-group metals, rare earths, tantalum and tungsten.
  Methodology: selected from 41 minerals on the basis of two criteria: risks of supply shortages and the economic impact thereof. Two types of risk are considered: 'supply risk' (based on the political-economic stability of producer countries, level of concentration of production in certain countries, potential for substitution and recycling rate) and 'environmental country risk' (based on risks due to weak environmental performance of producer countries that might endanger the supply of raw materials).

It is important to make a few observations here on these methodologies.

First, the quantification methods for determining a certain shortlist of 'critical minerals' depend very much on the specific calculation methods and thresholds that are being used, as illustrated by the examples listed above. For instance, both the EU and the US reports use the aspects 'supply risk' and 'economic importance' to classify the raw materials. The EU report on defining critical raw materials defines a material as critical when "the risks of supply shortage and their impacts on the economy are higher than for most of the other raw materials"[25]: i.e. a relative ranking. A threshold was then selected to define a criticality region, in which the raw materials exhibit comparatively high supply risks and economic importance (see Figures 4 and 5 below). Note that there is no unambiguous procedure to set the thresholds, which in fact are the product of a decision rather than a calculation.

Secondly, the methods used rely on a set of indicators which were chosen to describe the potential problems related to certain raw materials, such as the concentration of production, political stability, import dependence, environmental issues, etc. Analysing such resource criticality is usually based on annual data for the indicators used and thus only represents the situation for the reference year. Since values can change in a relatively short time (e.g. declining political stability) or gradually over decades (e.g. by concentration tendencies), these models might give hints to possible short-term supply bottlenecks but cannot be used for long-term scenarios. An illustrative example can be seen in Figure 3, which shows the changes in producing country concentration (measured by the Herfindahl-Hirschmann-Index) and in political and economic stability (measured by production-weighted World Governance Indicators) for tantalum between 1996 and 2009.

Studies from the '70s and '80s in fact followed a similar approach to recent studies. When comparing old and new criticality studies it becomes clear that although the raw materials regarded as critical have changed over the past decades according to technological and economic development trends, the way of looking at the problem has remained the same. Over the long term

[24] European Commission, *Critical raw materials for the EU*, Report of the Ad-hoc Working Group on defining critical raw materials, 30 July 2010. Available online at: http://ec.europa.eu/enterprise/policies/raw-materials/files/docs/report-b_en.pdf.

[25] European Commission, *Critical raw materials for the EU*, Report of the Ad-hoc Working Group on defining critical raw materials, 30 July 2010, p. 23.

the minerals identified as critical have almost never caused severe supply shortages, and in recent studies most of them are no longer regarded as critical. Employing this indicator-based method implies that the resulting lists of critical raw materials represent only a snapshot of a dynamic system. These results can thus hardly serve as predictive models.

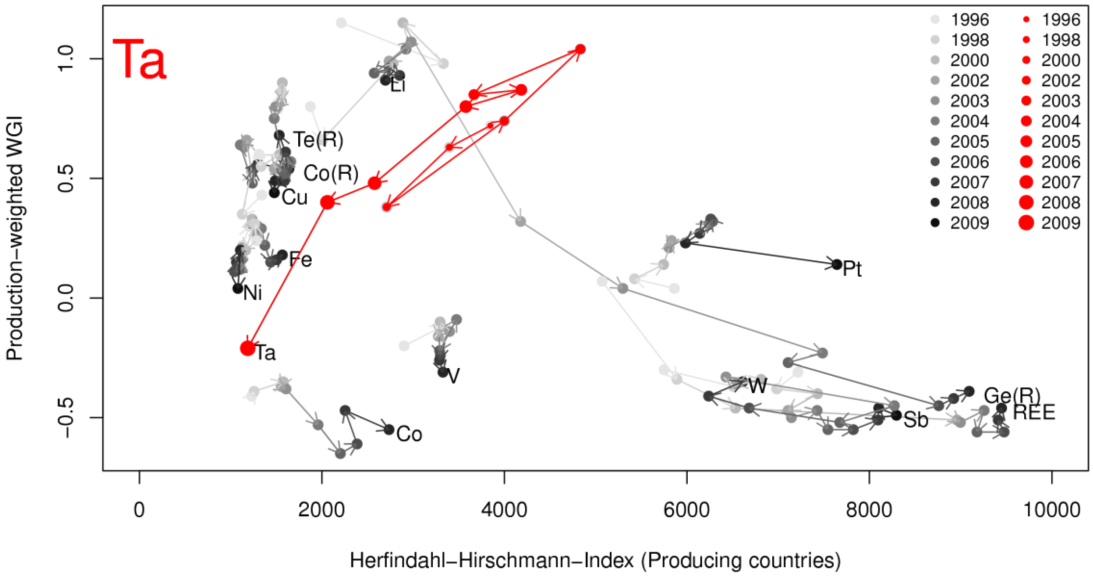

Figure 3: Evolution of tantalum, highlighted among some other minerals, in terms of producing country concentration (measured by the Herfindahl-Hirschmann-Index) and the political and economic stability of producer countries (measured by production-weighted World Governance Indicators) between 1996 and 2009,. Source: Fraunhofer ISI / L. Tercero Espinoza (image), BGR database and World Bank (data).[26]

Consequently, the resulting list might not capture all the potential problems. Whereas the generally accepted indicators certainly give some idea about potential risks, they may highlight some materials which are in fact not likely to cause any great problems that the market is not able to solve in the short or medium term, whereas they might miss some other issues that could eventually become major sources of political or economic tension.

[26] This graph has been prepared by Luis Tercero Espinoza from Fraunhofer ISI, and has been used in the presentation 'Defining Critical Raw Materials'by the authors at the POLINARES WP 2 Thematic Workshop in Paris, 1 June 2011. Available online at: http://www.polinares.eu/docs/events/polinares_events_tw2_minerals_criticality_presentation.pdf.

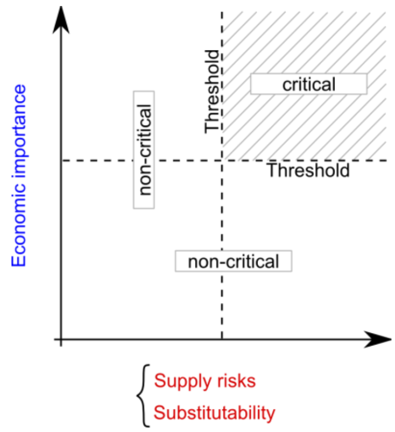

Figure 4: Schematic representation of the criticality concept as used by the Ad-hoc Working Group on defining critical raw materials for the EU, using the indicators 'economic importance' and 'supply risks' (including substitutability and recycling). Source: Fraunhofer ISI / POLINARES internal documents.

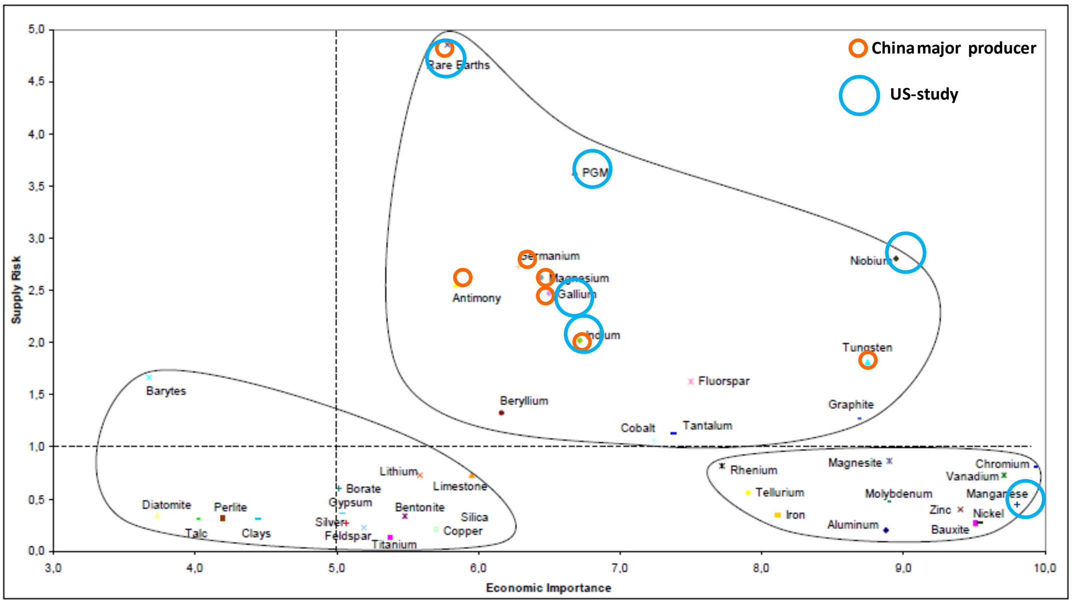

Figure 5: Correlation of results of the EU report (2010) and the US study on criticality (2008). Critical minerals (EU definition) for which China is the biggest primary producer are also indicated. Source (adapted from): European Commission, *Critical raw materials for the EU*, Report of the Ad-hoc Working Group on defining critical raw materials, 2010.

The example of 'technology minerals'

The case of 'technology minerals' is illustrative of the shortcomings of criticality studies in terms of their look at risk assessment. Many of the very large price spikes which have occurred in recent decades in mineral markets have been due to so-called 'technology minerals' and were caused by a sudden expansion in the demand for a mineral with very specific properties due to some technological innovation (often in the electronics industry). The current concern over rare earth elements also falls into this category. These price spikes and which particular mineral might be involved are extremely difficult to predict. Often the concerned markets for these specialty minerals are rather small (in terms of total tonnage and number of producing mines), causing concentration levels in a producer country (or company) that seem very alarming but that are in fact not so fundamental and often quite easy to overcome through diversification (e.g. by opening new mines in different countries). Furthermore, price increases in such 'technology minerals' often translate into only very limited price increases of the end-product, as they usually make up a minimal share of the overall cost. Such price increases can easily be borne by consumers in many cases, causing little detrimental economic effects. In other cases, higher prices have spurred innovation in substitution and resource efficiency that have mitigated the tight supply situations.[27]

On the other hand, resources that are traded in very large and liquid markets, such as copper, iron ore and coal, do not often figure in critical mineral shortlists. Yet given their size and often very significant and widespread economic impact, perceived unequal access can lead to serious political tensions. Pricing arrangements and whether or not there is an open, transparent functioning market in which all consumers can compete on an equal footing are often the essence of such tensions. Also, concerns about unequal access given to resource sector investments in certain countries can give rise to severe political disputes. Examples can be found, for instance, in the disputes between China and Australia over iron ore exports and their pricing system, and over protectionism and state interference in resource sector investments. These types of concerns that arise from certain resource markets are often not identified by conventional indicator-based criticality methodologies and require us to consider a different approach.

Finally, for studies with a long time horizon, having a shortlist of minerals might create a false sense of certainty that it is these minerals – and not others – that will be a problem in coming years and decades, whereas in reality, these risks depend largely upon political, economic and technological developments that are very hard to predict. It seems wise not to hide or neglect this uncertainty but rather to incorporate it into the approach of policy solutions, as this might very well influence what can be considered the best strategy for resource security.[28]

Different modes of criticality

The criticality studies that we discussed above have mostly focused on two major aspects of resource security: i.e., the risk of a supply disruption and the potential economic impact of such a disruption. These two aspects are then combined into one overall measure: the 'criticality' of the resource.

[27] We will elaborate on this issue with a historical case study on cobalt in the second 'follow-up' briefing paper.

[28] It should be noted here that the criticality study reports themselves very much acknowledge and emphasize the dynamic nature of resource markets and the 'snapshot' character of their results. However, this nuance is often lost in the debate.

However, we argue that first of all, the risks related to these two aspects are not adequately addressed in criticality studies, and secondly, that such an aggregate concept of criticality distorts the assessment of where major risks might appear. Of course, we recognise that there is always a difficult balance to strike between presenting results in a simplified but accessible manner and attempting to incorporate more subtlety and complexity in the message. However, we argue that lumping several concerns together in one overall 'criticality' value might in fact cause extra confusion instead of addressing them separately.

In fact, criticality studies acknowledge themselves that underneath such an aggregate notion there are several aspects of criticality that can be distinguished. Stepping back from a single aggregate score analysis for the 'criticality' of certain resources, we can name several 'criticality' categories:

- The 'criticality of supply' is the central part of all studies and discussions on raw materials security. This includes aspects such as the import dependence of consumer countries, the concentration of production in certain countries or companies, the availability of secondary raw materials and substitutes, price volatility, success of exploration and new projects coming into production. Included in this definition are the (geo)political risks associated with concentrated production taking place in countries of 'strategic distrust' (which could be termed 'political criticality') or in unstable countries.
- Social and environmental risks associated with raw materials production can be termed 'environmental/social criticality'. This includes conflict-area-related mineral production.
- The 'physical criticality' dealing with the question of whether the earth can provide the resources for future global demand.

Various aspects of criticality (and there might be more than mentioned above) play a role with regard to the supply of raw materials. Integrating all the different aspects into one single criticality value can make it more difficult to distinguish and assess the diverse sources of possible conflicts and might not point to relevant questions with respect to supply security.

This leads us to question whether it might not be better to examine the fundamental concerns which underlie the various aspects of criticality – concerns that are not so much related to a specific raw material but that are more general or 'generic'. We offer such an analysis in the section below.

Resource security: an analysis of concerns

To move forward from the discussion about which resources should be considered critical and why, we will take a step back to reflect upon what are actually our concerns and objectives related to resource security. This is in fact essential to be able to evaluate *any* approach to resource security and it will also allow us to verify what role criticality studies can play in identifying major risks related to access to resources. In this analysis, we also will distinguish between short-term concerns, dealing with our capacity to handle a sudden supply disruption, and more long-term strategic concerns.

The basic objective regarding resource security, whether it concerns energy or non-fuel minerals, is commonly defined as "ensuring an adequate supply at a reasonable cost", since a functioning supply chain is the basis of any economy.

Consequently, the primary concerns focus on the potential impact of supply disruptions and extreme price increases, caused either accidentally or intentionally[29].

(1) Accidental supply disruptions or price hikes

A first concern is that a supply disruption (and ensuing price hike) might be the result of events such as a natural disaster, technical failures, strikes or political instability in a major producing country.

(2) Intentional supply disruptions by the use of exports or pricing as a political instrument

Secondly, raw materials could be used as a deliberate instrument by some actors. Those in control of production or exports could use raw materials to gain political or economic power, e.g. by issuing embargoes, restricting exports or price gouging[30]. In such cases an artificial supply crisis (either real or feared) could place political pressure on other countries and cause disadvantages for the industries of countries depending on raw materials imports.

The first two concerns, supply disruptions and political (economic) dependence, reflect the fear of non-functioning markets. This non-functionality can have physical or political causes. In the first case unforeseen events or developments lead to a market failure, resulting in physical supply shortages. In the second case this malfunction is caused by the non-market-conform behaviour of a stakeholder (or a group of stakeholders). For such events to be problematic, a precondition is that there is a (group of) producer(s) with such a dominant position in the market that it can significantly influence total supply.[31]

Both concerns focus more on the short-term impact of a supply disruption or price hike. Probably the most well-known example of a politically motivated action related to energy resources is the oil embargo of 1973. An example in which political and economic aspects came together is the Russian-Ukrainian dispute over gas prices, which impaired the delivery of gas to Europe in 2006 and 2009 and which affected mostly south-eastern Europe. On the minerals side, there is the cobalt supply crisis caused by the civil war in Angola in 1978, which halted the export of cobalt coming from Zaire (now Democratic Republic of the Congo) – then accounting for 63% of the world's supply[32] – and the temporary halt of rare earth exports from China to Japan following a dispute in the East China Sea in

[29] Based upon work by Kalicki and Goldwyn (2005) and Le Billon (2005), the EU FP7 Polinares project identifies the following variety of sources that give rise to tensions and conflicts: "(1) Fears concerning the current or future availability of a resource: (1a) based on well-documented technical evidence of the availability of the resource; (1b) based on poor information or inadequate understanding of the available technical information; (1c) based on the actions of key actors, or based on interpretations of behaviour and perceptions of intent of key actors (i.e. the organisational structure of the market); (2) Fears relating to the current or possible future price of commodities; (3) Fears of insecure supply within the entire delivery chain; (4) Different perceptions of threats to human rights and environmental security relating to natural resources; (5) Legitimate commercial competition between corporations from different nations for access to energy and mineral resources; (6) Asymmetry in crisis mechanisms or unequal access to crisis mechanisms in case of a supply disruption; (7) Illegitimate rivalry between private parties for access to energy and mineral resources; (8) Illegal trade of mineral resources as a revenue source for rebel groups, terrorism, and organised crime" (EU FP7 Polinares, *Description of Work*, p. 6).

[30] The Study on Critical Imported Materials issued during the US Nixon Administration in 1974 includes an excellent summary of potential problems regarding the adequate supply of critical imported materials at reasonable cost. The potential problems listed are: Embargoes, Cartels, Greater Processing in Exporting Countries (i.e., a shift in the value chain), Supply Disruptions from events other than embargoes and Exorbitant Short-term Price Increases.

[31] This aspect is taken into account in criticality studies by analyzing the concentration of production.

2010. Historically there have also been repeated attempts at establishing producer cartels in the mineral sector[33].

Typical measures taken to guard against sudden supply disruptions are the creation of strategic stockpiles or reserves, e.g. strategic petroleum reserves such as held by the member states to the International Energy Agency and strategic stockpiles of selected minerals and raw materials such as held in the United States by the National Defense Stockpile.

In addition, there are concerns about problems that do not influence the stable supply of raw materials (at a reasonable cost) directly in the short term, but which are nonetheless related to the question of resource availability and access. Main themes in this second category of more long-term and strategic concerns are the following:

(3) Unequal market conditions, causing an uneven economic playing field

Tensions can arise when market conditions for the participating stakeholders vary. This need not lead to supply shortages but can cause unequal opportunities for countries, influencing economic competitiveness. Examples include:

- Different internal/external pricing of resources for different countries,
- Unequal access to crisis mechanisms in case of a supply disruption or unequal impact of a price hike (price asymmetries), and
- Unequal market access or investment opportunities.

All these might cause severe political tension. Regarding investment, conditions might not be equal for all companies. Resource sector investments have come under greater scrutiny in recent years. Particularly Chinese investment in resource-rich countries in Africa, Latin America and elsewhere is attracting attention. Also, Chinese investment and merger and acquisition attempts towards Western firms operating in the resource sector are closely watched, as several politically tense cases have illustrated. Related to the future development of resource markets and international trade and investment regimes, this is also an important theme.[34]

(4) Governance issues related to the resource sector

Finally, a concern related to the supply of raw materials is that extraction and production activities could be responsible for regional environmental and social problems and contribute to conflicts. An example is the concern about the role of the resource sector in some of the resource-rich countries, particularly in Africa. Examples of measures taken in this field are the Kimberley Process (dealing with so-called 'blood diamonds') and the current legislation on Conflict Minerals that is part of the Dodd-Frank Act (Section 1502) in the United States, which imposes the responsibility upon companies to ensure their mineral supplies are not related to any conflict zone.

---

[33] "[A]ssociations of producers and exporters were set up during late 1960s and early 1970s for all kinds of commodities including copper, iron ore, bauxite, phosphates, mercury, tungsten and silver". David Humphreys, "Minerals: Industry History and Fault Lines of Conflict", Polinares Working Paper, September 2010, p. 9.

[34] All issues mentioned here are elaborated in the second briefing paper, *Resource Security Risks in Perspective*, 2011.

Identifying the time-scale and seriousness of a problem

Actually, concerns often get mixed up in the debate and no distinction is made between short-term problems and long-term problems. Yet securing the capacity to deal with an unforeseen supply disruption without major economic or societal upheaval is a different problem than ensuring a sound basis for economic competitiveness and resource sector investments worldwide.

Concerning political interference in the resource sector, the power to use strategic control over resource production for political purposes can always be exerted, posing the risk of both a short-term and a long-term supply disruption. However, it should be taken into account that there are strong economic incentives that deter the use of control over resources as a political instrument.

A second point of attention is the need to investigate more closely what a potential supply disruption might actually entail. In particular, a distinction should be made between volume risk and price risk. Will there be a physical shortage of supplies, meaning that deliveries will be delayed or cancelled and that even for those willing to pay very high prices the required resource is not available? Or will the prices go up but the material will still be available for the highest bidder? In other words: will the market still continue to function, even in a crisis situation? Typically, supply shortages in the strict sense occur only rarely. More often, the price hike accompanying tight supplies will make the resource unaffordable to some consumers or force them to utilise alternatives, thus reducing demand.

Quite often, the worst fears are not that certain resources will be absolutely unavailable, but rather that the time lag between higher prices and the impact of demand destruction, additional supplies and all other countermeasures will last so long that there will be irreparable economic harm. Whether or not large company stockpiles exist for certain materials (e.g. rare earths) will make a big difference as to whether there will be a significant economic impact.

Hence, there is a need to be able to identify the time scale of the problem that is being faced: is this a 2-3 month problem, a one-year problem, a 5-year problem or a problem for the coming decades? Secondly, the potential impact needs to be better assessed: will a problem make some products more expensive or delay their production, or will it have an impact on the basic needs of society or vital functions of the state, such as maintaining law and order?

These questions call for deeper analysis of the several identified risks in the previous section. As these issues cannot be all addressed here, the second part of this twin briefing paper will follow up with a more in-depth analysis[35].

The need to understand the complexity and diversity of mineral markets

Finally, some of the fears surrounding resource availability seem to be caused by misconceptions about the functioning, complexity and diversity of resource markets[36]. A simplified view on the

[35] The second part of this 'twin' briefing paper, *Resource Security Risks in Perspective* (2011), is available for download at: www.clingendael.nl/ciep.

functioning of resource markets sometimes also leads to exaggerated concerns about resource availability in tight market conditions.

Very small, almost 'niche'-like mineral markets related to demand by a specific emerging technology function completely differently than the large base-metal commodity markets and will react differently to tension between supply and demand. Particularly for markets with small overall volumes and little total mining capacity, producer dominance and high price volatility are much more likely (see Figure 6). How prices are determined – whether a material is traded freely on the London Metal Exchange spot market or only sold bilaterally by long-term contracts – will make a big difference in the case of tight market conditions. Also, the production method of a certain material – whether it is mined as a principal mining product with 'dedicated mines' or as a by-product of other mining activities – will determine how supply will react to price fluctuations. Finally, problems due to the dependency on certain materials might not be caused by issues related to the mining phase of the raw materials but rather to bottle-necks or dependencies further up in the value-chain, e.g. in the refining stage or manufacturing of semi-products.

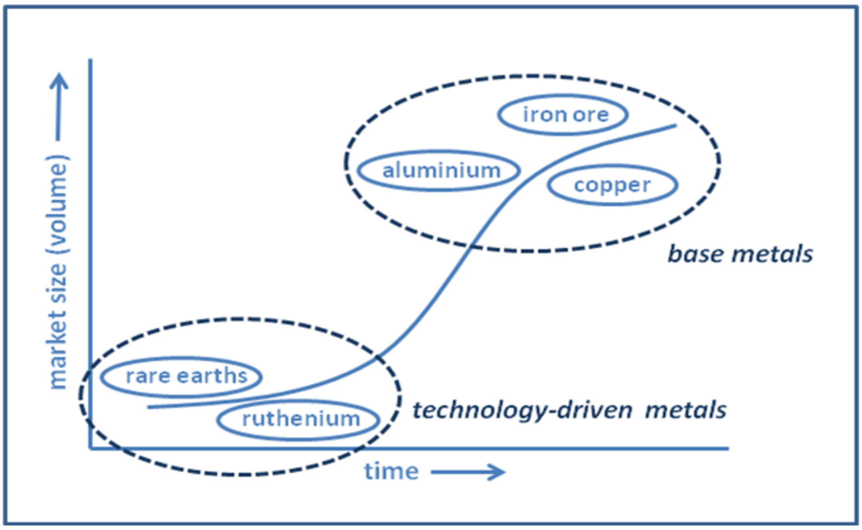

Figure 6. Sketch of dynamic market development: Size & maturity are a key factor in resource market behaviour and characteristics.[37]

Within the energy resource sphere, the markets of oil, gas, coal and uranium differ enormously as well. Oil is the one of the largest commodity markets, with circa 85 million barrels produced daily and a very large share traded on open transparent spot markets. For gas, due to its dependency on pipeline infrastructure, long-term contracts with oil-indexed prices are prevalent in most regions. Uranium has only a relatively small spot market (in volume circa one-tenth of the annual uranium demand of all nuclear reactors), and most deliveries are arranged through long-term contracts. An interesting additional factor here is the secondary source of supply via the dismantling of nuclear

[36] We only provide a brief introduction of this issue here. It is discussed more elaborately in the second briefing paper *Resource Security Risks in Perspective*, 2011.

[37] Note: this graph is illustrative and does not attempt to indicate real production growth patterns over time. It merely wishes to indicate that smaller mineral markets are not comparable in their functioning and characteristics to much larger markets, and that some problems will likely resolve themselves as markets grow in size.

warheads and recycled fuel, which accounts for about 15 to 20% of global supply[38]. For coal the story is completely different again, as it is mainly a domestic matter: only 16% of all coal is currently traded internationally, whereas the rest is consumed in the country where it is produced[39].

From these examples it can be inferred that in order to address the potential problems in energy and mineral resource markets, taking the varied characteristics of these resource markets into account is essential. A 'one-size-fits-all' approach to resource security problems is unlikely to be effective.

A second important observation is that the strength of economic principles seems to be often underestimated in the discussions about the impact of a supply disruption – in particular for minerals but to a lesser extent also for energy resources.

Basic economic principles will help to resolve emerging tensions, due to the embedded incentives of higher prices. These are:

a. resource efficiency (in the final product, e.g. using less of an expensive component),
b. more efficient use of the end-product (e.g. demand reduction),
c. substitution of the material by another material inside the same final product,
d. substitution of the end-product,
e. finding new sources of primary supply (e.g. more exploration and investment),
f. increasing secondary sources of supply (e.g. increasing recycling; only for minerals).

To illustrate these principles, in the case of oil used for transportation, this would translate into rising oil prices causing more pressure to: (a) produce and buy fuel-efficient cars, (b) drive less, (c) use bio-fuels instead of gasoline, (d) buy an electric (or other non-gasoline based) car or use public transport and (e) explore and invest in new oil supplies.

A recent example of what price incentives can achieve in terms of stimulating resource efficiency is provided by the solar panel manufacturing sector. Due to the extremely rapid growth of solar energy, poly-silicon production was unable to keep up with demand, and prices increased enormously. Ironically, poly-silicon is made from silicon, which is essentially sand and hardly a scarce resource. However, refining capacity (to convert silicon into poly-silicon) proved to be a bottle-neck, and spot prices for solar-grade poly-silicon increased from about $25/kg to more than $500/kg between 2003 and 2008[40]. In response, poly-silicon wafer (and panel) manufacturers were forced to make huge improvements in their poly-silicon usage per wafer to cut costs and decreased this ratio by circa 20 percent, from around 8 grams to 6.5 grams per Watt-peak (g/W_p)[41]. Since poly-

---

[38] Cameco, *Uranium 101*, 2011. Available online at: http://www.cameco.com/uranium_101/markets/ (Accessed 20 January 2011). Also see: World Nuclear Association, Uranium Markets, updated July 2010 (available online at: http://www.world-nuclear.org/info/inf22.html) and M.E. Dzhakishev, *Pricing in the Uranium Market,* 2002.
[39] World Coal Association, *Coal Market & Transportation*, 2011. Available online at: http://www.worldcoal.org/coal/market-amp-transportation/ (accessed on 20 February 2011).
[40] Nasdaq, Trefis Team, "Increase in Polysilicon Prices Could Hinder SunPower's Profitability", 2 February 2011. Available online at: http://community.nasdaq.com/News/2011-02/increase-in-polysilicon-prices-could-hinder-sunpowers-profitability.aspx?storyid=55973.
[41] "[W]hen p-Si was in short supply the industry aggressively drove p-Si usage efficiency (g/Wp) lower; great efforts were expended to trim wafer thickness, reduce kerf losses, and introduce alternative silicon purification techniques (e.g. upgraded metallurgical grade (UMG) silicon). Some wafer manufacturers drove thinner wafers, accepting yield loss due to breakage as

silicon remains an important price component of the overall solar panel (even with lower p-Si prices), these improvements have contributed permanently to a decrease in the price of solar panels[42].

The severe cobalt crisis in the late 1970s, which is analysed in the second of this twin briefing paper, points to the highly adaptive capacity of industry with regard to price spikes in the technology mineral sector.

Whereas for some of the resources considered (especially in the energy resource sectors) the ability to accommodate price hikes and short-term supply disruptions are limited, there are historical examples which illustrate how the above-mentioned processes have helped to overcome tight markets or price hikes without there being any significant lasting economic harm[43].

Conclusion: The case for a new approach to criticality

Studies of critical minerals are intended to be tools in helping to identify problems or tensions that might arise over the access to resources. Yet we have seen that criticality studies carry certain important limitations which should be properly acknowledged in order to obtain a sensible understanding of the energy and mineral resource markets.

In particular, much of the concern about minerals is driven by fears about the availability of ‘technology minerals’ such as rare earths (or, historically, cobalt and platinum group metals), coupled with a concern about meeting future high demand levels. Other triggers for alarm are high import dependency levels coupled with strongly concentrated reserves or actual production in certain countries or companies. These concerns have not changed over the past decades, but the raw materials identified as critical have changed according to the demand and supply structure of the industry sector and to the political conditions at the time of the analysis.

Looking at the key issues persisting over the last decades, we have identified four fundamental concerns:

- *Accidental supply disruptions or price hikes*,
- *Intentional supply disruptions by the use of exports or pricing as a political instrument*,
- *Unequal market conditions causing an uneven economic playing field*, and
- *Governance issues related to the resource sector*.

Other resource sector risks will directly or indirectly impact these four basic concerns. Of course, different materials will be the subject of different concerns. Some minerals run very low risks of suffering from accidental or intentional supply disruptions, but they might nonetheless cause serious concern because of governance issues (e.g. conflict minerals or resources with a high environmental impact). Others might be very important from the viewpoint of economic competitiveness. In general, criticality studies are well-suited to identifying risks related to short-

---

it was offset by the exorbitant cost of polysilicon.” Deutsche Bank, *Solar Photovoltaic Industry 2010 global outlook: Deja vu?*, 8 February 2010, pp. 12, 15. Available online at: http://65.181.148.190/renewableenergyinfo/includes/resource-files/solar%20pv%20outlook%20fitt_8%20feb%2010_pdf.pdf

[42] Poly-silicon costs accounted for more than half of the total solar module cost in 2Q 2008, according to Deutsche Bank.

[43] This theme will also be elaborated in the second briefing paper *Resource Security Risks in Perspective*, 2011.

term supply disruptions (both accidental and intentional) but miss out on the longer-term strategic concerns. They are also focused very much on the risks related to resource extraction rather than potential risks that might be present in the value chain as a whole.

It is therefore important to study the fundamental concerns with regard to Europe's long-term raw materials supply security. Understanding what type of conflicts, political conditions or developments in the resource market might influence the raw materials supply, including mining, refining and transport, is a necessary basis to discussing possible critical materials. Moreover, it should be acknowledged that it might not be possible to pinpoint what minerals will be critical in the coming decades. Basing policy on a more general framework and understanding of resource markets would likely be more sensible.