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# Critical minerals for the EU

**By Henrike Sievers, Bram Buijs and Luis Tercero**

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# 19 Critical minerals for the EU

*Henrike Sievers, Bram Buijs, Luis Tercero*

**Even if geological constraints do not account for future supply shortages and no physical scarcity is foreseeable, there might be supply risks in the future, possibly leading to a relative scarcity. The main risks for EU's future raw materials supply originate from other factors than the natural abundance of resources. The availability of natural resources needed for the European economy might be linked to geopolitical factors, such as the political stability of the producing countries, company and country concentration, social issues, trade distortions and lack of investments in exploration, mining and processing.**

**The European Commission published a study on "Critical raw materials for the EU"[1]. In the report "geological scarcity is not considered as an issue for determining criticality of raw materials within the considered time horizon of the study". Changes in the geopolitical-economic framework impact on the global raw material supply and demand are regarded as the most important.**

**The next chapter will summarize and evaluate the main aspects of the EU study, which is the most recent one in a row of several criticality assessments from different countries (USA, UK etc.).**

## *19.1 Historical background and introduction to resource criticality studies*

In recent times concerns are running high again with regard to possible scarcities of natural resources. Faced with the current concerns about supply shortages, it is important to realize that such concerns are a recurring theme throughout history, resurfacing mostly in response to tight market conditions and increasingly high prices.

For an important part, the fundamental cause for this recurrence lies 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, often leading to a pattern of 'hog cycles' of market slumps and price spikes.

Looking into the history of the energy and mineral mining sectors illustrates such market cycles and the corresponding political cycles of attention, concern and tension over resource

[1] "Critical raw materials for the EU". European Commission, Enterprise and Industry Directorate General, June 2010, http://ec.europa.eu/enterprise/policies/rawmaterials/documents/index_en.htm

availability. In addition, such cycles also cause shifts in the balance of bargaining power between consumer and producer countries, as well as host governments and companies involved in resource extraction, denoted by the *obsolescing bargain* principle. Related to this, these industry cycles also go quite some way in explaining the periodic resurgence of resource nationalism, as the increasing monetary value of extracted resources inherently has led to a greater politicization of control over them.

The essential concerns have mostly remained the same throughout history, focusing on the (potential) impact of accidental or intended supply disruptions on 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 long term. Specifically, oil and gas have been treated with much concern, due the (perceived) limitations of expanding and diversifying supplies, whereas coal and uranium have led to less political tensions due to a wider resource base and a diversified field of producers.

Concerning mineral resources, concerns about specific raw materials have fluctuated very much with market circumstances and have seen changing sets of raw materials that were thought be critical at certain times in history, by certain countries. A couple of examples can serve as an illustration:

1975 the European Community published a communication on the security of the community's raw material supply [1]. It states that, though a geological scarcity is not foreseeable, the supply with 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 nationalization of mining companies and the increasing tendency to process raw materials in the producer countries. Several measures are 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 are mentioned as supporting measures.

The Commission states that the problem exceeds the national frame of the member states and that therefore a common solution of all European states should be aimed at. It suggests creating a body within the Community that pools knowledge and information on raw materials. It emphasizes that only with a systematically organized, close collaboration of all relevant disciplines the knowledge base can be created, which is needed to shape a European resource policy. 1975 raw materials of concern for European countries were aluminum, chromium, copper, tin, iron ore, manganese, platinum, tungsten, zinc and phosphates.

The Study of Ad Hoc Group Established by NSSM 197 / CIEPSM 33 in the mid 1970s also considered bauxite, chromium and platinum as critical to the U.S. economy.

The report *Strategic Critical Nonfuel Minerals: Problems and Policy Alternatives* (1983) by the U.S. Congressional Budget Office states in that the US dependence on raw material imports might be a problem. The study on strategic and critical minerals identified chromium, cobalt, manganese and platinum-group metals (PGMs) as critical to the US economy.

According to Humphreys (1995) the end of the Cold War changed the political perception of resource security in the 80s and 90s. After the end of the Cold War concerns over the security of resource supply became less important. The notion that a free, globalized market will provide sufficient raw materials and that an active resource policy is not needed anymore prevailed. Instead of discussions on supply security environmental and social aspects gained attention and were included in laws.

During the Cold War the thinking in blocks (spheres of influence) prevailed and there was a tendency towards raw material subsistence within these blocks.

While centrally planned economies were more or less self sufficient, the western countries already in those days were heavily reliant on imported metals from the developing economies. Interregional raw material flows were restricted by the political conditions. After the Cold War had ended interregional trade flows increased and a real globalization of the raw material supply took place. The changes also led to the end of local price regimes and were replaced especially by the trade of metallic raw materials at the LME. States increasingly withdraw their activities from the resource sector and a number of former state companies were privatized in the 90s (CVRD in Brazil; Cerro Verde and Tintaya in Peru etc.). Exploration activities of the mining companies, for a long time focused on Australia, Canada and the USA, now were directed to other regions, especially South America.

During this period China becomes a major raw material exporting country. Partly raw materials formerly produced in western industrialized countries, were now produced in China (e.g. RE).

Since the turn of the millennium China's demand for resources increased sharply. While the demand for e.g. the internationally traded iron ore grew at 2.2% between 1980 and 2000, an annual increase of 8.2% between 2000 and 2008 [3].

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[2].

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. In the new millennium China became the biggest raw material consuming country. To supply its domestic industries with the resources needed, China imposes export quotas, duties and subsidies. Chinese companies invest globally in mining projects. Those activities are supported by the Chinese government, if they are not state controlled companies anyway. From 2005 on the increasing demand for raw materials led to a sharp increasing of prices, which only came to an end by the global financial crisis in 2008 when the raw material prices crashed. Since 2009 the prices recovered again and partly reached new record highs.

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

The increasing demands of China for raw materials, coupled with protectionist measures and securing the access to resources in foreign countries, evoke concerns over the security of the supply with resources in the EU and other industrialized countries. The EU as well as it's the member states are paying attention to the topic of raw material supply security (publishing studies, resource strategies, programs to increase the resource efficiency etc.). In 2010 the European Commission published a report on critical raw materials, which classifies 14.

From state engagement in the resource sector in the 70s as a result of the discussion on supply security against the background of the political conditions of the Cold War, and a company dominated free, globalized market in the 90s, at the end of the 2000s the pendulum seems to swing back towards increasing state engagement at least in the discussion raw material needs and supply. This might at the end lead to an increasing state control or influence on 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 1).

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.

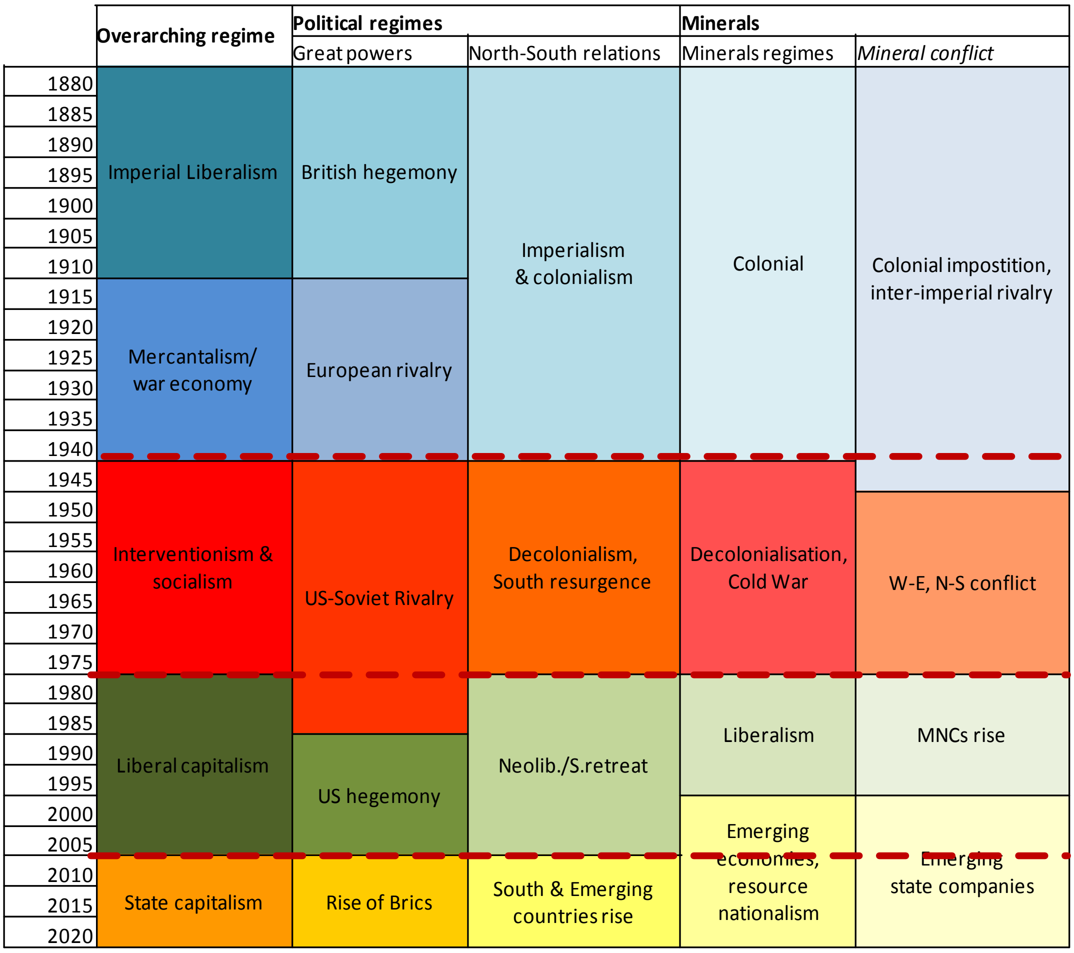
An explanation of the change in the political attention to resource policy between the 1970s and late 2000s is given in various accounts[3]. First, the end of the Cold War changed the political perception of resource security in the 1980s and 1990s. After the Cold War, with the hope of more markets opening, 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[4]. 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[5]. 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.

[3] 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.
[4] 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.
[5] E.g. CVRD in Brazil, Cerro Verde and Tintaya in Peru.

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).

China's increasing demand for raw materials, the country's protectionist measures and steps toward securing access to foreign resources, has recently evoked concerns in other 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[6]. 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 ones, through strategic partnerships and policy dialogues".[7] 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.




[6] 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.
[7] Communication by the European Commission, "Tackling the Challenges in the Commodity Markets and in Raw Materials". COM(2011) 25 final, Brussels, 2 February 2011.

**Figure 1: Regimes relevant to the resource sector and overarching regimes according to POLINARES WP1 (POLINARES, 2010).[8]**

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 1).

In recent years there has been an increasing trend towards trying to quantify the supply risks and (economic) impact of supply disruptions of certain materials. This has led to the use of indicators, for instance the Human Development Index or World Bank's Worldwide Governance Indicator as a measure of political stability and the potential for supply disruptions. As for the economic impact of certain minerals, estimates are often made by means of calculating the value of the products or overall industry sectors dependent upon a certain material, adjusting for the potential of substitution or increased resource efficiency.

*Material Security. Ensuring resource availability for the UK economy* (2008):
Critical minerals: Gold, rhodium, platinum, strontium, silver, antimony and tin.
Methodology: selected out of 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).

*Minerals, Critical Minerals, and the U.S. Economy* (2007):
Critical Minerals: Indium, Manganese, Niobium, Platinum-Group Metals (PGMs), Rare Earths (RE).
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 sector and the difficulty, expense and time of finding a suitable substitute) and the supply risk (based strong import dependency on a dominant supplier).

*Critical Materials Strategy* (2010) by the U.S. Department of Energy:
Critical Minerals: Five Rare Earth elements (Dysprosium, Neodymium, Terbium, Europium and Yttrium) and Indium.
Methodology: selected out of 14 minerals on the basis of two criteria: supply risk and importance to clean energy technologies.

*Critical Raw Materials for the EU* (2010) by Ad-hoc Working Group on Defining Critical Raw Materials and European Commission:

[8] 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.

Critical minerals: antimony, beryllium, cobalt, fluorspar, gallium, germanium, graphite, indium, magnesium, niobium, platinum-group metals (PGMs), rare earths (REs), tantalum, tungsten.
Methodology: selected out of 41 minerals on the basis of two criteria: risks of supply shortages and the economic impact. Two types of risk are considered: ‘supply risk’ (based on 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”[9]: 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. 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 2, 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 and other selected metals 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 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.

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

[9] 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.

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.

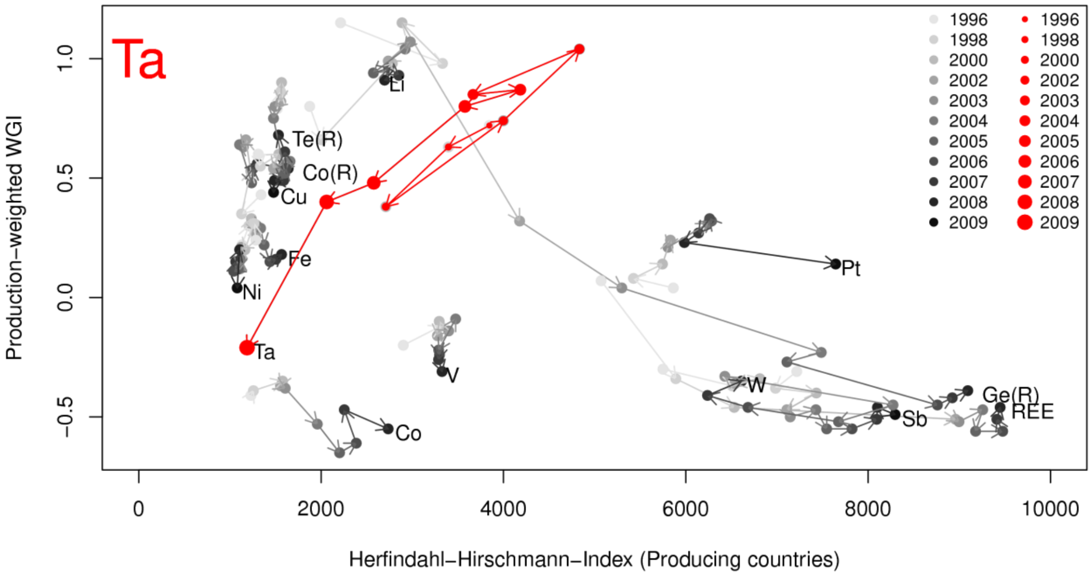



**Figure 2: Evolution of tantalum, highlighted among some other minerals, in terms of producing country concentration (measured by the Herfindahl-Hirschmann-Index) and the political and economic stability of producer countries (measured by production-weighted World Governance Indicators) between 1996 and 2009, (Source: Fraunhofer ISI / based on data from the BGR database and World Bank (data)).[10]**

## 19.2 Criticality assessment for the European Union

Diverse nations and regions have conducted assessments into how "critical" non-energy raw materials are for their respective economies. Critical raw materials are generally identified by using a simultaneous assessment of economic importance of the raw materials and perceived risks arising from the use/dependence on these raw materials. Because of the direct relevance to the POLINARES project, the recent criticality assessment conducted for the European Union is briefly described in the following sections. This assessment was conducted by an Ad-hoc Working Group within the framework of the EU Raw Materials Initiative with participation of BGR and Fraunhofer ISI, parallel to the work for POLINARES.

### 19.2.1 Defining criticality

The Ad hoc Working Group 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."[2] In practice, this means that a relative ranking of non-energy raw

[10] 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 .

materials in the two selected dimensions (economic importance and supply risk)[11] was prepared. A threshold was then selected to define a criticality region, as shown in Figure 3, where the raw materials exhibit comparatively high supply risks and economic importance. Note that there is no unambiguous procedure to set the thresholds, which in fact are the product of a decision and not of calculation.

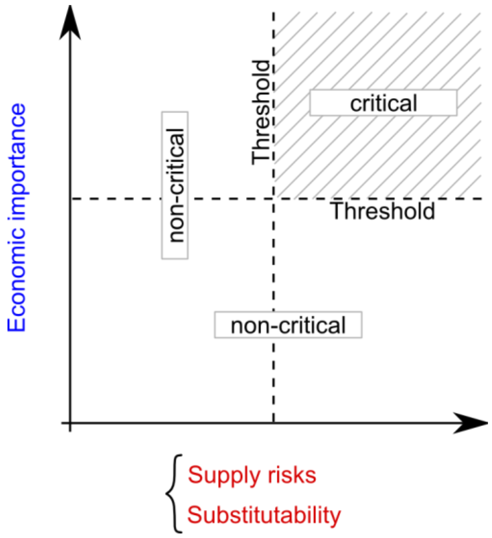



**Figure 3: Schematic representation of the criticality concept as used by the Ad-hoc Working Group on defining critical raw materials for the EU using the indicators "economic importance" and "supply risks" (including substitutability and recycling).**

## 19.2.2 Methodology

### *19.2.2.1 Economic importance*

Because the value of a raw material to the economy far surpasses the value of the raw material itself, the working group assessed the economic importance of non-energy raw materials by the value of the products that depend on these. In order to do this, the end uses for each raw material were identified along with the corresponding percent of net demand. In a second step, each end-use was assigned to a "megasector", defined by a collection of related NACE sectors at the three and four digit level, as outlined in table 1. The assignment was done as far down the value chain as possible. The value of each megasector was accounted for in terms of gross value added as published by Eurostat in the Structural Business Statistics database.

[11] We note that the assessment also included an indicator of the environmental performance of the producing countries, but the inclusion of this indicator did not change the results of the exercise because of the strong correlation with the indicators of supply risk (see Methodology, below).

**Table 1: Summary of "megasectors" as used in the calculation of economic importance (as used in the EU study "Critical Raw materials to the EU")**

| Megasector | Short description |
|---|---|
| Aeronautics, trains, ships | Ships and boats, railway, tramway locomotives, rolling stock, aircraft and spacecraft. |
| Beverages | Beverage industry in general (not agriculture). |
| Chemicals | Production of organic and inorganic chemicals. |
| Construction material | Ceramic tiles, bricks, concrete, cement, plaster, building stone, metal structures and parts of structures, builders' carpentry and joinery of metal, ceramic household and ornamental articles, etc. |
| Electrical equipment | Electric motors, generators and transformers, electricity distribution and control apparatus, insulated wire and cable, lighting equipment and electric lamps, household electrical equipment. |
| Electronics & ICT | Office machinery and computers, accumulators, primary cells and batteries, electronic components, television, radio transmitters and sound or video equipment, telephony, medical equipment, industrial process control equipment, optical instruments, etc. |
| Food | Food processing in general (not agriculture). |
| Mechanical equipment | Mechanical power equipment (except aircraft, vehicle and cycle engines) including e.g. engines and turbines, pumps and compressors, taps and valves, driving elements, non-domestic cooling and ventilation equipment, machine tools, machinery for diverse purposes and non-electric domestic appliances. |
| Metals | Smelting and refining of ferrous and non-ferrous metals, including casting and shaping into containers, wiring, etc.; powder metallurgy; treatment and coating of metals; recycling of metal waste and scrap. |
| Mining of metal ores | Ferrous and non-ferrous metals. |
| Other final consumer goods | Furniture, cutlery, tools and general hardware, tools, locks and hinges, musical instruments, sports goods, games and toys, jewellery and related articles, coins. |
| Paper | Pulp, paper and paperboard, corrugated paper and paperboard and of containers of paper and paperboard, household and sanitary goods, paper stationary, wall paper, etc. |
| Pastic, glass, rubber | Rubber tyres and tubes, other rubber products plastic plates, sheets, tubes and profiles, plastic packing goods, flat & hollow glass, glass fibres, technical glassware, abrasive products. |
| Pharmaceuticals | Pharmaceuticals in general, including preparations for dentistry. |
| Refining | Refining of petroleum and processing of nuclear fuel. |
| Road transport | Agricultural tractors, electrical equipment for engines and vehicles, motor vehicles, trailers and semitrailers, parts and accessories for motor vehicles, motorcycles and bicycles. |

The aggregation of the values was done as follows: let the share of net use of raw material $i$ be denoted $A_{is}$, and let the value of the corresponding using megasector be denoted by $Q_s$, then the relative economic importance of the raw material, $EI_i$, can be aggregated by the equation

$$EI_i = \frac{1}{GDP} \sum_s A_{is} Q_s$$

where the gross domestic product of the EU is taken as a common denominator. Note that $\sum_i A_{is} = 1$. In words, the economic importance is the weighted sum of the gross value added of the megasectors consuming a given raw material, using the share of net consumption in each megasector as the weight of the megasector in the sum; this sum is then divided by the European GDP. Therefore, the quantity $EI_i$ seeks to characterize the economic impact of a sudden supply stop, assuming this leads to a complete stop of production in the affected megasectors. While this is an overestimation, the Working Group deemed this to be the most pragmatic way of assessing economic impact in face of the data limitations.

### 19.2.3 Supply risks

The risks in supply were considered to arise from a combination of several factors, namely:

1. lack of substitutes,
2. low recycling rates,
3. high concentration of producing countries, and
4. poor governance of the producing countries.

These four risks are brought together into a single indicator, denoted $SR_i$, calculated as follows:

$$SR_i = \sigma_i \left(1 - \rho_i\right) HHI_{WGI}$$

where $\sigma_i$ accounts for the substitutability of the raw material, $\rho_i$ is the fraction of demand that is currently met by recycling, and $HHI_{WGI}$ simultaneously characterizes the concentration of production at the country level and the governance in those countries. These three components are explained in more detail below. Notice that, according to this methodology, low substitutability and recycling rates as well as concentration of production in few countries with poor governance all increase the supply risks. Thus, it is not possible to see which combination of factors led to a particular result without considering the components of the equation separately.

#### *19.2.3.1 Concentration of production at the level of countries*

The last term in the equation above characterizes both the concentration of production at the country level and the governance in those countries. This is done by modifying the Herfindahl-Hirschmann-Index in two ways: (1) by performing the calculations using production at a country level instead of at a company level, and (2) by multiplying the share of production of each country by its score in the World Governance Index, published regularly by the World Bank.[12] This index includes six categories: voice and accountability, political stability, government effectiveness, regulatory quality, rule of law, and control of corruption. The calculation of this index then takes the form:

$$HHI_{WGI} = \sum_c \left(S_{ic}\right)^2 WGI_c$$

where $WGI_c$ is the World Governance Index score of country $c$ and $S_{ic}$ is the percent share of country $c$ in world production of raw material $i$.

12 http://info.worldbank.org/governance/wgi/sc_country.asp

#### *19.2.3.2 Import dependence*

Note that the approach described above excludes the degree of import dependence of the EU. Nevertheless, this indicator was calculated on the basis of EU production data and official trade statistics obtained from Eurostat and the United Nations (UN comtrade).

The trade codes used for this were selected as close to the raw material as possible, i.e. ores and concentrates instead of semi-finished products. The list of codes was then expanded according to the input from experts from within the Working Group or contacted by members of the Working Group. Despite these efforts, it was not possible to establish a homogeneous data quality across all raw materials, especially for those traded in small quantities such as gallium or tantalum.

Nevertheless, the collected data on import dependence is useful because different measures can be applied by the European Commission inside the EU than outside of it, where alternatives are more restricted. Thus, import dependence was included in the report though it was not used to measure supply risks.

#### *19.2.3.3 The role of recycling*

The risks assigned to the producing countries do not apply to material recycled within the EU. Assuming this production to be riskless, the factor $(1-\rho_i)$ serves to scale the risk of primary production to account for recycling. At the extreme, if the recycling rate is zero, the risks of primary production apply to the entire supply of raw material $i$. The higher the fractional recycling rate, the smaller the term $(1-\rho_i)$ becomes, reflecting that the risks associated with primary production do not affect the entire supply of the raw material considered. This relation is presented schematically in figure 4. Notice that this assessment only considered recycling from old scrap in the calculation of supply risk.

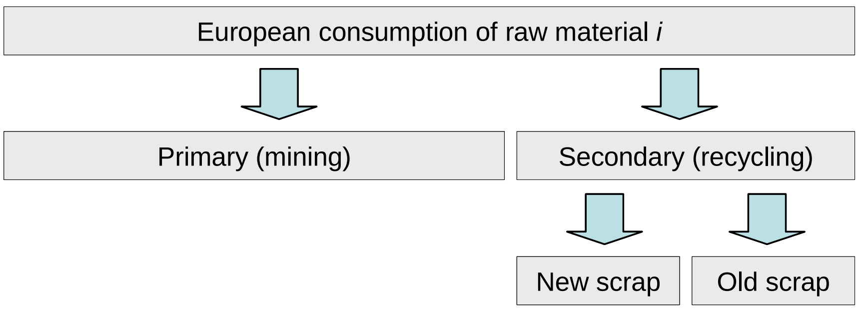



**Figure 4: Schematic representation (not to scale) of recycling as included in the EU criticality exercise: only recycling from old scrap was considered in the calculation of supply risk.**

#### *19.2.3.4 Accounting for substitutability of raw materials*

Raw materials are used in products to provide a function. Thus, it is possible to substitute one raw material for another provided the intended function is adequately performed by the substitute. This potential for substitution is captured by the term $\sigma_{is}$, which is the estimated substitution potential for raw material $i$ for a particular end-use sector $s$. Thus, a weighted sum may be constructed as

$$\sigma_i = \sum_s A_{is} \sigma_{is}$$

to characterize the overall substitutability of a raw material. As before, $A_{is}$ is the share of net consumption of raw material $i$ in end-use sector $s$, and $\sigma_{is}$ the corresponding substitutability index. This index was estimated by expert judgement and subject to review by experts internal and external to the Working Group. Possible values are:

- 0,0 Easily and completely substitutable at no additional cost
- 0,3 Substitutable at low cost
- 0,7 Substitutable at high cost and/or loss of performance
- 1,0 Not substitutable

In the context of the supply risk equation, this means that if a raw material is not substitutable, the risks of production (after recycling is accounted for) fully apply to the value of the raw material, as expressed by its economic importance. In contrast, if a raw material was immediately and fully substitutable at no additional costs, the risk associated with primary production would not apply to the economy because the same function could be performed by a different raw material, leading to no supply risk.

Notice that this approach does not explicitly include the supply risks associated with the substitute. These are included in the estimates of $\sigma_{is}$ on the basis of expert judgment.

### 19.2.4 Environmental risks

The report also considers the risk of a supply stop due to environmental concerns, e.g. the closing of mines due to the adoption of stricter environmental regulation. It is argued that this risk is higher in countries with poor environmental management, which may enter a process of modernization of their environmental regulations. To assess the quality and effectiveness of environmental regulation, the Environmental Performance Index[13] was selected. The calculation of environmental risk was fully analogous to that described above, but substituting $WGI_c$ by the Environmental Performance Index.

#### 19.2.4.1 Results of the criticality assessment of the European Commission

A total of 41 raw materials were considered in the assessment. The evaluation of the 41 raw materials led to the 2D distribution shown below. The subset of raw materials classified as critical are contained in the upper right of Figure 3. These are (in alphabetical order): antimony, beryllium, cobalt, fluorspar, gallium, germanium, graphite, indium, magnesium, niobium, the platinum group metals, rare earths, tantalum and tungsten.

[13] http://epi.yale.edu/

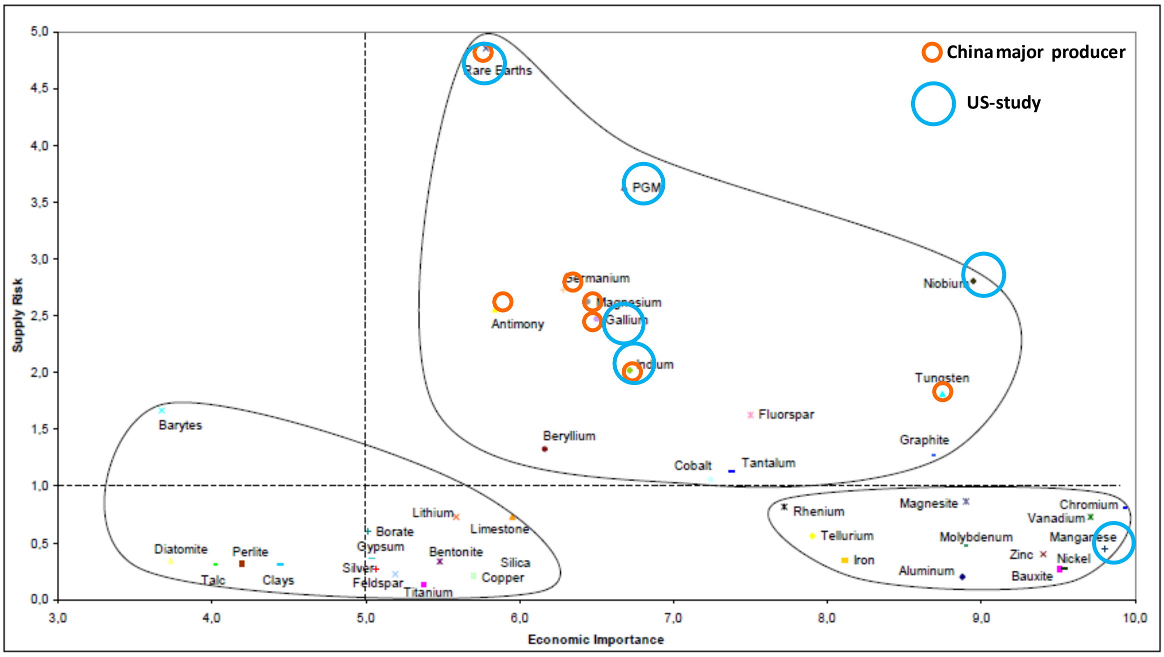



**Figure 5: Correlation of results of the EU report (2010) and the US study on criticality (2008). Critical minerals (EU definition) for which China is the biggest primary producer are also indicated. Source (adapted from): European Commission, *Critical raw materials for the EU*, Report of the Ad-hoc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

## 19.3 Different modes of criticality

Although short lists of critical raw materials are well suited for focusing the attention of policy makers and highlighting current issues, the lumping together of a variety of very different factors can in fact obscure the nature of the underlying challenges. Moreover, the necessity of a common data base for the comparison of different raw materials prevents many relevant issues from being considered in the analysis. Finally, the heavy reliance on historical data and the dynamic nature of raw material markets preclude the exclusive use of criticality studies to guide long-term policy.

Instead, when thinking about a time frame of several decades, we argue that it is more useful to step back and separately consider the different aspects that are hidden behind the lists or rankings of critical raw materials. These are for example:

The criticality of supply is the central part of all existing studies and discussion on raw material supply 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'. Also included are 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.

### 19.3.1 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[14].

*(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,

[14] 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).

e.g. by issuing embargoes, restricting exports or price gouging[15]. 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.[16]

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[17] – and the temporary halt of rare earth exports from China to Japan following a dispute in the East China Sea in 2010. Historically there have also been repeated attempts at establishing producer cartels in the mineral sector[18].

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

[15] 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.
[16] This aspect is taken into account in criticality studies by analyzing the concentration of production.

[18] "[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.

- 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 despite its modest extent. 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.[19]

*(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.

## 19.4 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 especially with regard to long-term criticality. The approaches to assess criticality as described above have their strength with regard to possible short-term shortages and can give useful hints to companies and also countries for securing their resource supply over the next years. Those short-term criticality analyses will point to existing risks in the supply chain or in producing countries and point to specific measures that can be taken to ensure a continuous raw material supply. Those options might include the diversification of supply sources or research for substitution. They will always aim at lowering the risk of supply shortages in the near, foreseeable future.

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.

This implies that the definition of critical raw materials might be helpful especially the industry and for some shorter term political actions, but is not suitable for long- term predictions. To assess the criticality Europe's raw material supply some underlying key

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

concern with regard to raw material security have to be identified. These will contribute to monitor future developments on the resource markets against political, economic and technical developments.

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-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.

**Further reading**

The aspects discussed above were further elaborated in two recently published studies.

The papers entitled “Critical thinking about critical minerals – assessing risks related to resource scarcity” and “Resource security risks in perspective - complexity and nuance” where jointly written and published by CIEP (Clingendael International Energy Program) and BGR (Bundesanstalt für Geowissenshcaften und Rohstoffe) as Clingendael Briefing Papers in November 2011 and represent a cooperative work of the work packages 2 and 3 of the POLINARES project. Both studies can be found in Annex 1 of this project report.