Resource efficiency – what are critical metals and how scarce are they?

Prof. Dr. Mario Schmidt

Institute for Industrial Ecology, Pforzheim University, Tiefenbronner Str. 65, 75175 Pforzheim, mario.schmidt@hs-pforzheim.de

Abstract:

The prices of commodities have risen sharply in recent years. Many metals that play a central role in high-tech products are scarce. We even speak of strategic or critical metals. The scarcity is not defined solely geologically, but also in a socio-economic context. Recent studies show the limitations that arise for technical innovations. Policy-makers in Germany and the EU address the subject in corresponding roadmaps. The VDI is developing a standard framework under the heading “resource efficiency”. The status of the standardization work is presented.

1. Rising prices and high environmental pollution

A look at the development of commodity prices over the past decades shows that there has been a fundamental change during the last seven or eight years (Fig. 1). Not only the price of crude oil climbed parallel with the good economic situation in the years 2007 and 2008. The prices of industrial raw materials in particular increased exceptionally steeply too. They recovered quickly after the economic collapse at the end of 2008, and in 2011 were even higher than the peak in 2008. This is attributed chiefly to the demand from the upsurging national economies in Asia, led above all by China.

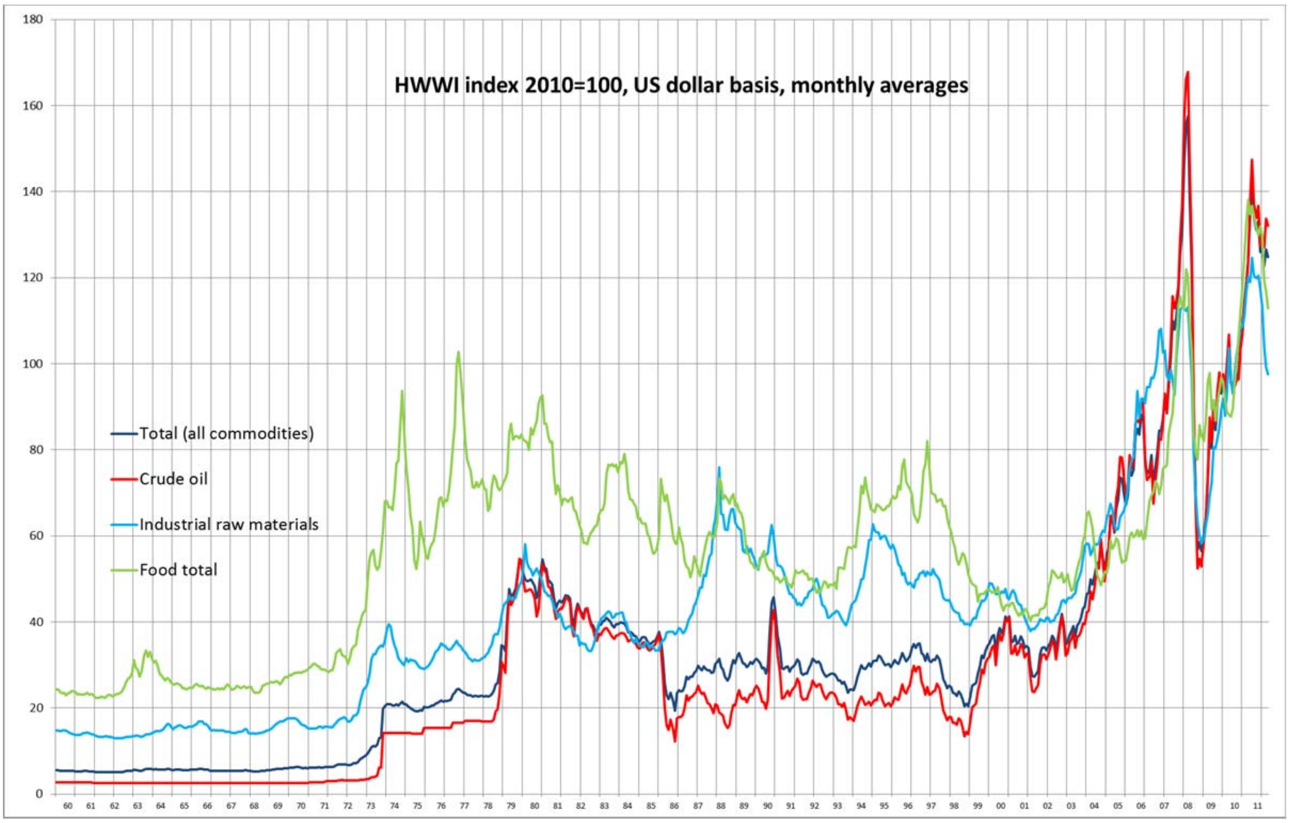

Fig. 1: HWWI-Index of world market commodity prices in US-$ since 1960. Own representation.

This price development reflects a quantitative scarcity of raw materials due to a strong increase in demand. However, alongside this quantitative shortage there has also been a qualitative change: Industry needs ever more exotic commodities for new technologies. One popular example of this is the role played by the rare earth elements. A study produced by Roland Berger points out that just three years ago the global market volume for these 17 metals was 2.4 billion Euro. By the end of 2011 the market volume had grown to about 27 billion Euro. In 2011 around 137,000 tons of these raw materials were used, approx. 30 percent of them for glass and ceramics production and around 20 percent for the production of magnets, for example for electric motors in the automotive industry or in wind turbine generators. Rare earth elements are also needed for catalytic converters (19 percent), for metal alloys and batteries (18 percent), or in the lighting appliances industry, for example for LED lamps (7 percent).

A further impressive example of this qualitative development is the number of chemical elements that are needed in electronic microchips. Whereas in the 1980s eleven elements from the chemical periodic table were required, in the 1990s the figure had increased to 15 elements, and after the year 2000 it climbed as high as over 60 elements. To produce a mobile telephone today it is necessary to use over 40 different chemical elements (SATW 2010).

These quantitative and qualitative changes lead to a third important point – the environmental impacts of mining and processing the raw materials. These are increasing altogether. The beginning of the 20th century saw an annual per capita consumption of resources of 4.6 tons; in the year 2005 this figure had doubled per head of population and year (Krausmann et al., 2009). A low ore content of many exotic raw materials and declining yields lead to a situation in which ever greater efforts have to be made to extract the commodities. A look at the CO2 emissions connected with producing and providing one kilogram of metal shows that 1 kg of iron involves roughly the same amount of CO2 emissions (approx. 1 - 2 kg), 1 kg of aluminium about ten times the quantity, 1 kg of silver 100 times the quantity, and 1 kg of gold nearly 20,000 times the quantity (see Tab. 1).

Tab. 1: Carbon footprints for extracting and providing some metals

Metal	**Carbon Footprint kg CO_2-Equiv./kg**	**Metal**	**Carbon Footprint kg CO_2-Equiv./kg**
Cadmium	0,80	Antimony	12,9
Iron	1,7	Tin	17,2
Lead	2,1	Lithium	21,1
Manganese	2,6	Chromium	26,8
Copper	3,2	Rare Earths (Neodymium)	38,6
Zinc	3,4	Magnesium	73,8
Titanium	4,6	Silver	101
Tellurium	7,5	Indium	154
Molybdenum	7,7	Gallium	205
Cobalt	8,3	Tantalum	260
Nickel	10,9	Platinum metals[a]	14.823
Aluminium	12,4	Gold	18.727

Source: Ecoinvent v2.2 database (May 2010) using IPCC2007 GWP100a factors

In many countries mining and extracting raw materials involve major ecological consequences. Across the world, three quarters of the active mines are located in areas that are valuable under nature conservation aspects or are subject to high water stress levels (WRI 2006). Many mines lie in developing countries that lack a strong civil society for enacting laws and monitoring operations. Nearly a quarter of the active mines are in countries with weak governance structures. In 2009, Ernst & Young rated climate consequences as No. 5 out of 10 strategically important mining business risks on a global scale. Water scarcity was ranked No. 13 (EY 2009). The Öko-Institut in Darmstadt recently drew attention to the environmental risks of mining rare earth elements (Schüler et al. 2011).

One interesting example of this is China, which plays a key role in connection with many strategic commodities. For instance, while China is admired for its economic growth of up to 10 % a year, the costs of environmental damage caused by air and water pollution are officially estimated at approx. US-$ 100 billion a year – equivalent to nearly 6 percent of China’s GDP. In other words, a large part of this economic growth is achieved at the cost of the country’s natural capital (World Bank 1997, 2007). Accordingly the economic growth is anything but sustainable.

Consequently there is both an economic and an ecological interest in deploying the raw materials sparingly and handling them efficiently.

2. Resource-optimists and resource-pessimists

How will prices develop in the future, especially the prices of rare earth elements? For many decades now the scarcity of mineral raw materials has repeatedly been the subject of speculation and discussion. The “resource-pessimists” fear physical scarcity and exhaustion of the geological deposits, while the “resource-optimists” assume that the scarcity lies in an imbalance between supply and demand and therefore generally represents only a temporary problem (SATW 2010). After all, rising prices and the regulatory function of the market advance technological progress in the mining and processing of expensive raw materials and foster substituting other, cheaper substances for them in products.

The truth presumably lies somewhere between these two extreme positions. For example, the current scarcity of rare earth elements on the global market is attributable to China’s present monopoly position. Under geological aspects, rare earth elements are not “rare”. However, China currently dominates the world market, mining and processing 95 percent of these key commodities, and aims to use its resources more strongly for its own production operations. Exports are greatly restricted. It will take years to build up alternative mining capacities in other countries. And in fact there are very few deposits of enriched ores worth mining, for the physical frequency of elements in the earth’s crust says nothing about whether they can be mined cost-efficiently.

A further problem lies in the fact that there are no separate mines for many metals. Instead, they are mined as by-products of ‘Major Metals’ (Hagelüken und Meskers, 2010). If the price of a special metal rises, this by no means justifies mining larger quantities, for the volumes are determined by the mining of the major metals, for example copper, lead, tin or uranium. The rare earth elements too are by-products and originate from a few combination minerals such as monazite or bastnaesite. As a result the price elasticity of these metals is low. Accordingly rising demand for an individual metal is not simply satisfied by increasing production levels.

Substituting other elements in products often also encounters limits in practice. After all, if one metal is to be replaced by another, it will need to have similar properties, and generally it is obtained from the same source. For instance in Europe, the use of lead for example was banned in solders. It can be replaced by tin, silver, indium or bismuth, but the latter three are by-products of lead mining. As less lead was mined as a result of the ban, the pressure of price on the other metals increased (Hagelüken und Meskers, 2010).

3. The entropy problem in recycling

For these reasons recycling will have a key role to play in commodity supplies in future. There are vast “hidden stocks” of raw materials in the industrialised countries, especially in large cities. It is estimated that the centre of Sydney contains for example copper resources of 600 kg per inhabitant (UNEP 2011). The concentration of raw materials here represents an advantage that will subsequently facilitate extraction. The industry speaks of “urban mining”.

On the other hand anthropogenic raw material stocks are widely scattered and show hardly any potential for exploitation. Electronic equipment, distributed worldwide, is a key example of this situation. Although a collection system for used equipment exists for instance in Europe, many items are passed on for second-hand or third-hand use in other countries without the infrastructure for collection and recycling. The raw materials are then practically lost, as the entropy is too great and the outlay for collecting the products and hence the raw materials again would be immense. It is estimated that the 10 billion mobile telephones sold worldwide until 2010 contain 2500 t silver, 240 t gold, 90 t palladium, 90,000 t copper and 38,000 t cobalt (Hagelüken 2010), as well as other raw materials such as for example the rare earth elements.

High recycling rates of 50 % and more are only customary for metals such as iron, aluminium, copper, or the alloy metals manganese, niobium or molybdenum, and the precious metals. However, for the special metals such as for example the rare earth elements, indium, tellurium or tantalum, the recycling rates are low and generally lie below 1 % (UNEP 2011). On the other hand, the anthropogenic stocks of rare earth elements are increasing rapidly. For the year 2007, the stocks of rare earth elements in products were estimated at 448,000 t, including 144,000 t cerium and 137,000 t niobium (Du and Graedel 2011). The metal niobium that is important especially for permanent magnets can be found in computers (40,000 t), in audio systems (31,000 t), in wind turbines (18.000 t) and in cars (18.000 t).

4. Critical raw materials

During the past few years various studies have explored what raw materials, especially metals, are critical or of outstanding or strategic importance for the economy. Geological scarcity, such as is frequently discussed in public, is less crucial here. Instead, the relevant issue is whether the raw materials are available on the market in sufficient quantities and quality. The supply risk can for instance be influenced by delivery monopolies, by political and/or economic instability of the main suppliers, by difficulties in substitution and by low recycling levels of the raw material.

In 2010 the EU rated 14 out of a list of 41 materials examined as critical (EU 2010) and developed strategies for a resources policy from these data (EU 2011) along the lines of their economic significance and the supply risk for the materials (Fig. 2). Other analyses address the issue under the aspects of vulnerability and supply risk (IZT / adelphi 2011). Fig. 3 shows the raw materials with the highest criticality in cluster VI. These include germanium, rhenium and antimony. Cluster V, rated as “highly critical”, includes tungsten, rare earth elements, gallium, palladium, silver, indium, tin, niobium, chromium and bismuth.

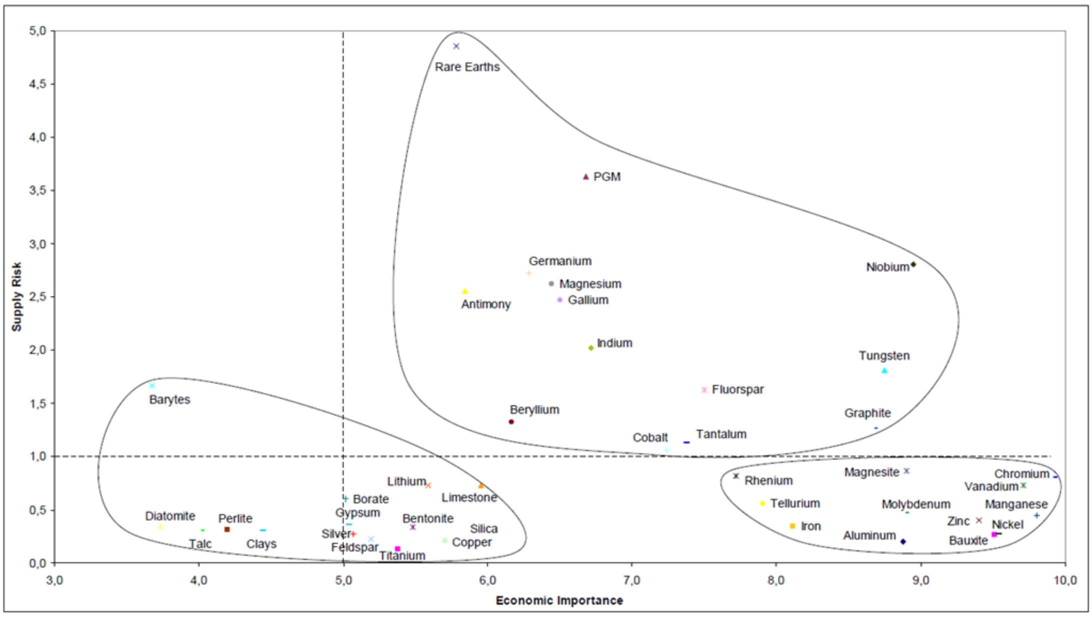

Fig. 2: Critical metals as defined by the EU (in the top right-hand cluster). Source: EU (2010).

One feature of germanium is its great significance for technologies of the future, such as fibre optic cable, photovoltaics or infrared sensors. Germany accounts for a very high share of global consumption of this metal – around 15 to 25 %. This status is compounded by high supply risks due to dependence on China and a low level of global reserves. Rhenium is indispensable in technologies of the future such as high-efficiency aircraft turbines and power stations. The supply risk lies partly in the strong concentration of companies – especially one dominating company from Chile. Germany also accounts for a very high share of gallium use (15 to 25 %), with growing consumption by forward-looking technologies in the ICT and photovoltaic sectors. Moreover gallium is very hard to recycle and is only obtained as a by-product (IZT / adelphi 2011).

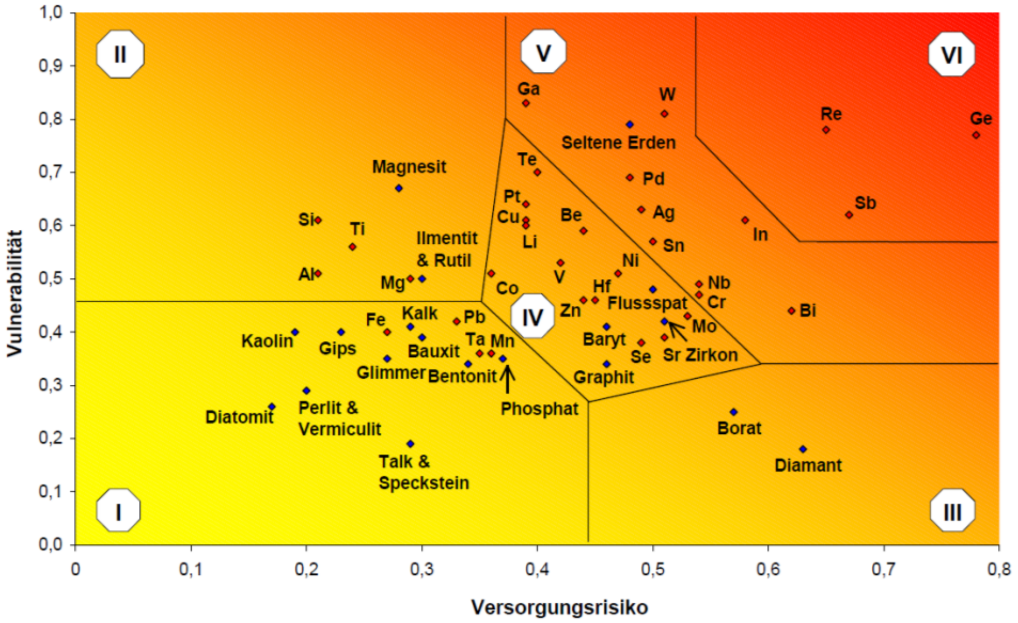

Fig. 3: Criticality rating, vulnerability and supply risk of 52 raw materials for Germany. Source: IZT/adelphi (2011).

5. Resource efficiency

The challenge for the future therefore lies in thrifty use of these resources and recycling as far as possible in closed loops. This is advisable on both economic and ecological grounds. Manufacturers and developers of new products, especially in the high-tech segment, are expected to think not only about new product properties, but also about how the products can be collected again after their use phase and be recycled at low cost. The catch phrase currently used for this is “resource efficiency”.

The Association of German Engineers (VDI) is now developing a set of guidelines for resource efficiency that is to be published in 2013. The planned VDI Guideline 4097 also addresses the objective of efficient use of resources. According to this, the overarching goal is to conserve natural resources, especially

- by reducing the use of raw materials (including water),
- by reducing the amount of land used and avoiding its degradation,
- by reducing environmental pollution,

and thus to maintain the bases of life for present and future generations.

Complementary objectives – such as economic goals – can be pursued at the same time provided that they do not run contrary to the overarching objective. This covers for example cost reduction and special consideration of commodities that are expensive or in short supply on the market. Industry is particularly interested in this. However, it is especially important to consider conservation of natural resources holistically in terms of both time and space. For products, this means considering the entire life cycle – from mining and extracting the raw materials, production, distribution and use, right through to recycling and waste disposal. This is the only way to realise concepts for the future in which scarce raw materials are used in closed loops as far as possible and sufficient quantities of important metals are available for high-tech applications in future too.

6. Bibliography

Du, X., Graedel, T.E. (2011) Global In-Use Stocks of the Rare Earth Elements: A First Estimate. Environmental Science & Technology 45, 4096-4101.

Erdmann, L., Graedel, T.E. (2011) Criticality of Non-Fuel Minerals: A Review of Major Approaches and Analyses. Environmental Science & Technology, 45, 7620–7630

Ernst & Young (2009) Strategic business risk report 2009. Mining and metals. Executive summary.

EU (2010) Critical raw materials for the EU. Report of the Ad-hoc Working Group on defining critical raw materials. Brussels.

EU (2011) Ressourcenschonendes Europa – eine Leitinitiative innerhalb der Strategie Europa 2020. KOM(2011) 21. Brussels.

Hagelüken, C. und Meskers, C.E.M. (2010) Complex Life Cycles of Precious and Special Metals, in: Graedel, T., and van der Voet, E. (eds.) Linkages of Sustainability. Strüngmann Forum Report 4. Cambridge, MA: The MIT Press.

IZT / adelphi (2011) Kritische Rohstoffe für Deutschland. Identifikation aus Sicht deutscher Unternehmen wirtschaftlich bedeutsamer mineralischer Rohstoffe, deren Versorgungslage sich mittel- bis langfristig als kritisch erweisen könnte. Im Auftrag der KfW Bankengruppe. Berlin.

Krausmann, F., Gingrich, S., Eisenmenger, N., Erb, K.H., Haberl, H. and Fischer-Kowalski, M. (2009) Growth in global materials use, GDP and population during the 20th century. Ecological Economics, 68(10): 2696-2705.

Schüler, D. et al. (2011) Study on Rare Earths and Their Recycling. Final Report for The Greens/EFA Group in the European Parliament. Öko-Institut Darmstadt.

Schweizerische Akademie der Technischen Wissenschaften SATW (2010) Seltene Metalle. Rohstoffe für Zukunftstechnologien. SATW Schrift Nr. 41, Zurich.

UNEP (2011) Recycling rates of metals. A status report. Geneva.

World Bank (1997) China 2020. Clear water blue skies. China’s environment in the new century. Washington D.C.

World Bank (2007) Cost of pollution in China. Economic estimates of physical damages. Washington D.C.

World Resources Institute (2003) Mining and critical ecosystems. Mapping the risks. Washington D.C.

Speaker: Prof. Dr. Mario Schmidt

Biography: since 2010: director of the study programme “Resource efficiency management”
since 2002: director of the Institute of Applied Research
since 1999: professor of environmental management at Pforzheim University
1991-1999: senior consultant at IFEU GmbH Heidelberg
1989-1990: officer at the ministry for environment of the German federal state of Hamburg
1985-1989: research assistant at Institute of Energy and Environm. Research Heidelb. e.V.