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Scarce metals - Applications, supply risks and need for action

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Abstract: In the past few decades, scarce metals have become increasingly relevant for emerging technologies, which are, *inter alia*, expected to play a significant role in the transition to a sustainable post-fossil society. This has raised concerns about whether the supply of such metals is secure and, if so, whether the ecological and social impacts associated to scarce metals supply would not counteract the expected benefits of emerging "clean" or "green" technologies, in particular. This paper presents typical applications of scarce metals, addresses associated supply risks and considers interventions required for a more sustainable governance of these raw materials. In particular, it shows that for a more sustainable governance of scarce metals, significant knowledge gaps still have to be overcome. Interventions will be necessary on different societal levels involving stakeholders at multiple points along the scarce metals life cycle.

Keywords: ICTs, Life cycle thinking, Recycling, Scarce metals, Supply risks, Sustainable governance.

Introduction

In the past few decades, scarce metals have become increasingly relevant for emerging technologies, which are, *inter alia*, expected to play a significant role in the transition to a sustainable post-fossil society (Angerer *et al*., 2009; U.S. DOE, 2010). Regarding information and communication technologies (ICTs), scarce metals are required, among others, for computer chips (gold, platinum group metals (PGM), tungsten), flat screens (indium), micro-capacitors (niobium, tantalum), solder (silver, tin) or batteries (cobalt, lithium).

As a consequence, a debate has been initiated on whether the supply of such metals is secure and, if so, whether the ecological and social impacts associated to scarce metals supply would not counteract the expected benefits of emerging "clean" or "green" technologies, in particular (European Commission, 2010; Stamp *et al*., 2012).

Geochemically "scarce metals" refers to metals with average concentrations in the earth crust below 0.01% w/w (Skinner, 1979) and includes elements such as

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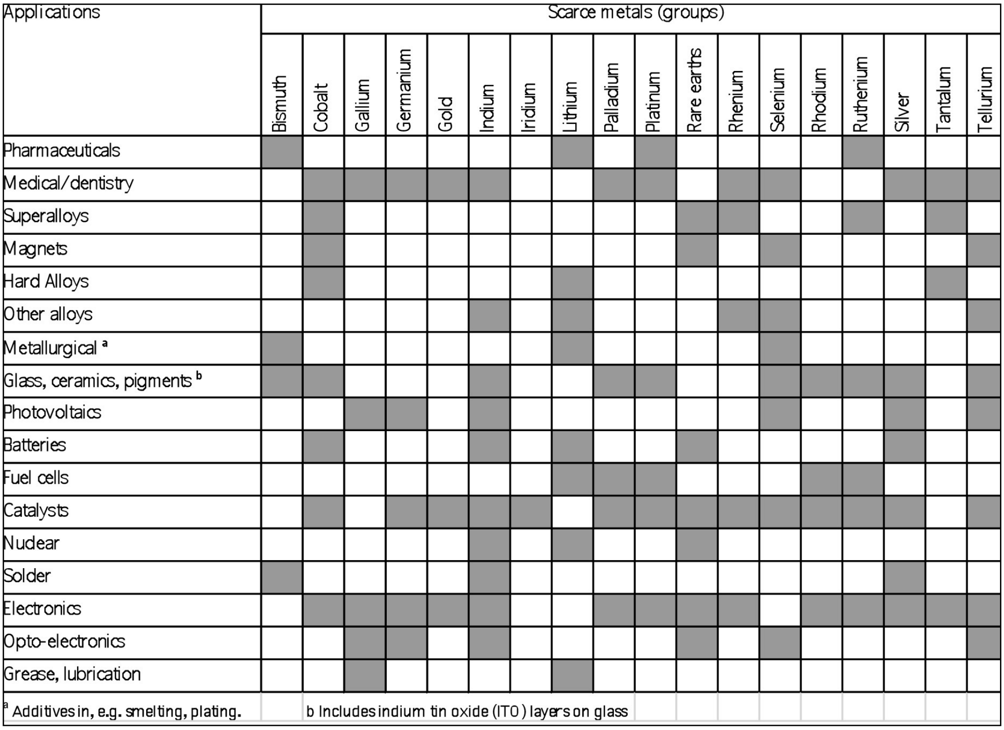
gallium, germanium, gold, indium and lithium; the platinum group metals (PGM) iridium, osmium, palladium, platinum rhodium and ruthenium; the rare earths, scandium, yttrium, lanthanum and the lanthanide series; and tantalum.

Scarce metals supply is considered to be a multi-factorial issue (National Research Council, 2008: Wolfensberger Malo *et al*., 2008; Wäger *et al*., 2010). Among the supply determinants are geological, technological (Reuter *et al*., 2005; Hagelüken and Meskers, 2010), environmental (Mudd, 2007a, b; Norgate *et al*., 2007; Giurco *et al*., 2010), and geopolitical factors (Corfield, 2010; Kim, 2010; Yu, 2010).

In the following discussion, some typical applications of scarce metals will be presented, associated supply risks and their implications addressed, and the need for action identified.

Scarce metals applications

The application of scarce metals in existing products and technologies is widespread. Figure 1 gives an overview of such applications for some selected scarce metals.



Applications	Scarce metals (groups)																	
	Bismuth	Cobalt	Gallium	Germanium	Gold	Indium	Iridium	Lithium	Palladium	Platinum	Rare earths	Rhenium	Selenium	Rhodium	Ruthenium	Silver	Tantalum	Tellurium
Pharmaceuticals	■							■		■					■			
Medical/dentistry		■	■	■	■	■			■	■		■	■			■	■	■
Superalloys		■									■	■			■		■	
Magnets		■									■		■					■
Hard Alloys		■						■									■	
Other alloys						■		■				■	■					■
Metallurgical [a]	■							■					■					
Glass, ceramics, pigments [b]	■	■				■			■	■			■	■	■	■		■
Photovoltaics			■	■		■							■			■		■
Batteries		■				■		■			■					■		
Fuel cells								■	■	■				■	■			
Catalysts		■		■	■	■	■		■	■	■	■	■	■	■	■		■
Nuclear						■		■			■							
Solder	■					■										■		
Electronics		■	■	■	■	■			■	■	■	■		■	■	■	■	■
Opto-electronics			■	■		■					■		■					■
Grease, lubrication			■					■										

[a] Additives in, e.g. smelting, plating. b Includes indium tin oxide (ITO) layers on glass

Figure 1. Products and technologies in which scarce metals are used according to (Hagelüken and Meskers, 2010).

As can be seen from Figure 1, a particularly broad range of scarce metals is employed in catalysts, the medical/dentistry domain and in (opto-)electronics, including solder.

A comprehensive study on future demand for scarce metals addressed 32 emerging technologies (Angerer *et al.*, 2009). It concluded that, in the year 2030, the demand for gallium, germanium, indium, neodymium, scandium and tantalum may exceed the worldwide production required to cover the 2006 demand of the investigated technologies by factors from 1.0 (tantalum) to 4.0 (gallium) (see Table 1; figures updated according to (Elsner *et al.*, 2010)). A significant increase in demand from green and clean energy technologies, in particular, is also expected by other studies (Buchert *et al.*, 2009; U.S. DOE, 2010; Schüler *et al.*, 2011).

Table 1. Demand indicators (ratio of total metal demand from selected emerging technologies to metal production in 2006) for selected scarce metals in the years 2006 and 2030 according to (Angerer *et al.*, 2009; Elsner *et al.*, 2010).

	Demand indicator 2006	**Demand indicator 2030**	**Future technology responsible for demand increase**
Gallium	0.18	3.97	Thin-film photovoltaics, Integrated circuits, WLED
Indium	0.40	3.29	Displays, Thin-film photovoltaics
Scandium[1]	0	2.31	Fuel cells (SOFC), Alloying element for aluminium
Germanium	0.28	2.20	Glass fibre cables, IR optical technologies
Neodymium[1]	0.23	1.66	Permanent magnets, Laser technology
Platinum[2]	0	1.35	Fuel cells, Catalysis
Tantalum	0.40	1.02	Micro capacitors, Medical technology

[1] a rare earth; [2] a PGM

Supply risks and their implications

Recently, several research projects and working groups have addressed potential supply risks and 'criticalities' of scarce metals. Pursuant to a definition of the *ad hoc* working group on defining critical raw materials of the European Commission (European Commission, 2010), a material is termed 'critical' when the risks of supply shortage and their impacts on the economy are higher compared with most of the other raw materials.

To evaluate supply risks or criticalities, different scopes and methodologies were applied (Behrendt *et al.*, 2007; Buchert *et al.*, 2009) and the U.S. Department of Energy (U.S. DOE, 2010) addressed specific technologies (electrical and electronic equipment (EEE), "green technologies" comprising electrical EEE, photovoltaics, batteries and catalysts, and clean energy technologies comprising electric vehicles, energy-efficient lighting, photovoltaics and wind-turbines, respectively). The Committee on Critical Mineral Impacts on the U.S. Economy of the National Research Council (National Research Council, 2008) and the *ad hoc* group of the European Community (European Commission, 2010) each referred to a specific economic context (the U.S. and the European Union economy, respectively). Several other studies at a national level, which are not considered here, were performed in countries such as Austria, France and the UK.

In the study of the *ad hoc* working group of the European Commission (European Commission, 2010), the criticalities of 41 selected non-energy raw materials were evaluated based on their supply risk, their economic importance and their "environmental risk". The working group considers 14 out of these 41 raw materials or raw material families to be most critical (for the scarce metals among them see Figure 2), with comparatively high supply risks mainly due to the concentration of their production on a few countries (Brazil: niobium and tantalum; China: antimony, fluorspar, gallium, germanium, graphite, indium, magnesium, rare earth elements, tungsten; Democratic Republic of Congo: cobalt, tantalum; Russia: PGM), often associated with low substitutability of the raw materials, and low recycling rates (European Commission, 2010).

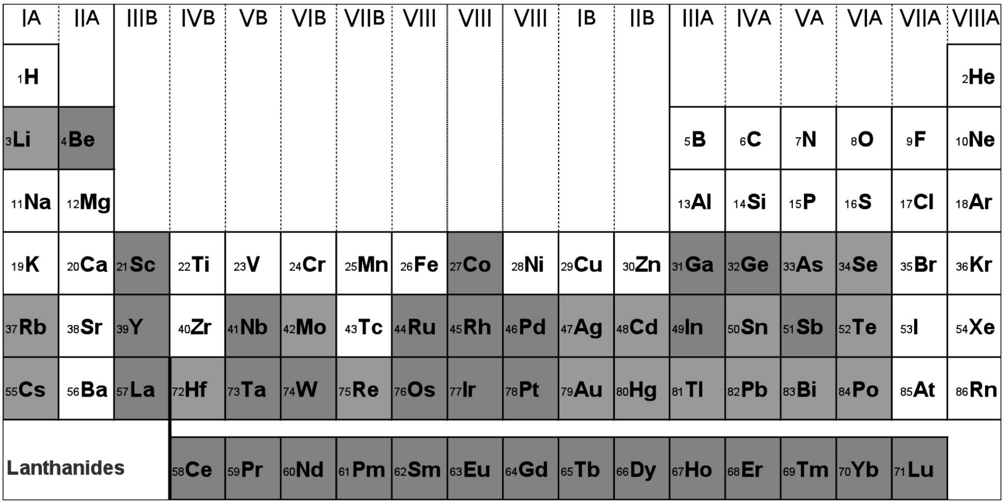


Figure 2. Scarce metals considered to be critical according to the ad hoc working group of the European Commission (in dark grey; light grey cells represent other geochemically scarce metals) (European Commission, 2010). In the report, the rare earths (scandium, yttrium, lanthanum and the lanthanides) were addressed as a group.

According to the above-mentioned studies antimony, cobalt, gallium, germanium, indium, niobium, PGM, rare earths and tantalum appear to be the most critical scarce metals (Wäger *et al.*, 2012). However, this list of most critical scarce metals has to be interpreted with care, since the scopes and methodologies of the studies differ from each other, and the criticality of a metal is subject to high temporal dynamics, triggered by altering geopolitical conditions, for example (Erdmann and Graedel, 2011).

The environmental dimension has until now not been systematically included in criticality assessments. According to some authors (Giurco *et al*., 2010; MacLean *et al.*, 2010), the impacts for producing a specified amount of metal are expected to increase due to falling ore grades; the exploration and opening of new mining sites such as those for rare earths outside of China is expected to put additional pressure on ecosystems and the local population.

The impact of using different resource types in a product or service has been investigated by Notter and Stamp (Notter *et al*., 2010) (Stamp *et al.*, 2012), who looked at the lithium required for electric vehicles on three different levels: resource provision (1 kg of lithium from each of brine, spodumene or sea water), product (1 kg of battery) and mobility service (1 vehicle km). While the results indicate that the environmental impacts of the lithium supply chain will probably only become an issue for e-mobility if seawater is eventually used to meet the demand for Li_2CO_3, further investigations are required for other scarce metals resources, products and services.

Figure 3 shows the environmental impacts for the actual production of 1 kg of metal for different scarce metals, compared to those for base metals such as aluminium, copper, and zinc. The environmental impacts per kg of metal differ significantly, with lowest values for base metals and highest values for precious metals such as gold, palladium, platinum or rhodium. However, when multiplied with the actual amounts of metals produced per year, the environmental impacts associated with mining, extraction and refining of metals are still highest for more abundant base metals such as iron, chromium, aluminium nickel and copper (UNEP, 2010).

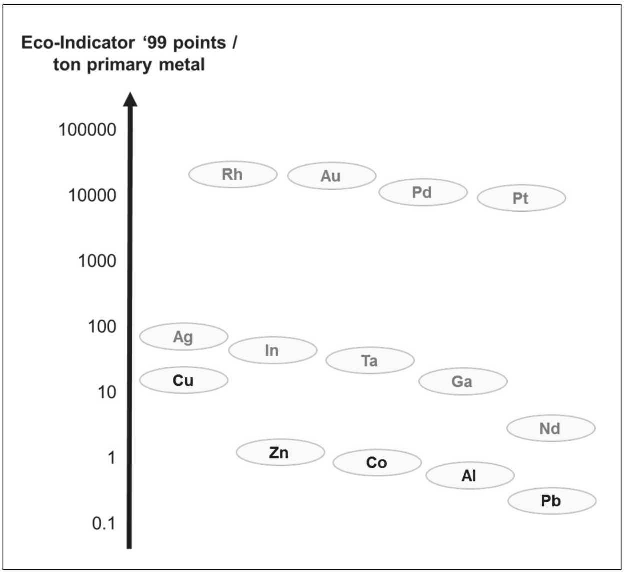


Figure 3. Aggregated environmental impacts (Eco-Indicator '99 points, (H/A)) for the production of each 1 metric ton of selected traditional industry metals (in dark grey) and scarce technology metals (in light grey), based on ecoinvent 2.1 data and economic allocation (Goedkoop and Spriensma, 2001; ecoinvent Centre, 2009).

Need for action

Taking into account the supply risks associated with scarce metals, together with the environmental and social impacts associated with primary and secondary scarce metals supply, efforts towards a more sustainable governance of these metals are urgently needed. A sustainable governance of scarce metals should be based on the following principles at least (Wäger *et al*., 2012): (i) conserve, as far as possible, primary resources for future generations; (ii) avoid dissipation into the environment and into material fractions, from which scarce metals are not recovered (for example the plastics fraction resulting from a mechanical pre-processing of Waste Electrical and Electronic Equipment (WEEE) (Chancerel *et al.*, 2009)); (iii) minimise environmental impacts of primary and secondary metals production; and (iv) secure supply for technologies which are essential for a transformation to a sustainable society. Furthermore, such a governance framework must adopt a life cycle perspective, i.e. address all phases of the scarce metals life cycle, from mining and extraction, through use, to recovery and disposal, and provide support for at least the following three distinct levels: knowledge provision, specific interventions along the scarce metals life cycle, and the institutional setting (Wäger *et al*., 2012).

A tentative, incomplete overview of specific intervention domains for a sustainable governance of scarce metals is given in Figure 4. On the *demand side*, though difficult to achieve in a consumption-driven society focused on economic growth, increasing sufficiency may be considered as a primary goal towards sustainable governance of scarce metals. On the *supply side* substitution, efficiency, reuse and recycling as well as an environmentally and socially responsible production process are major cornerstones.

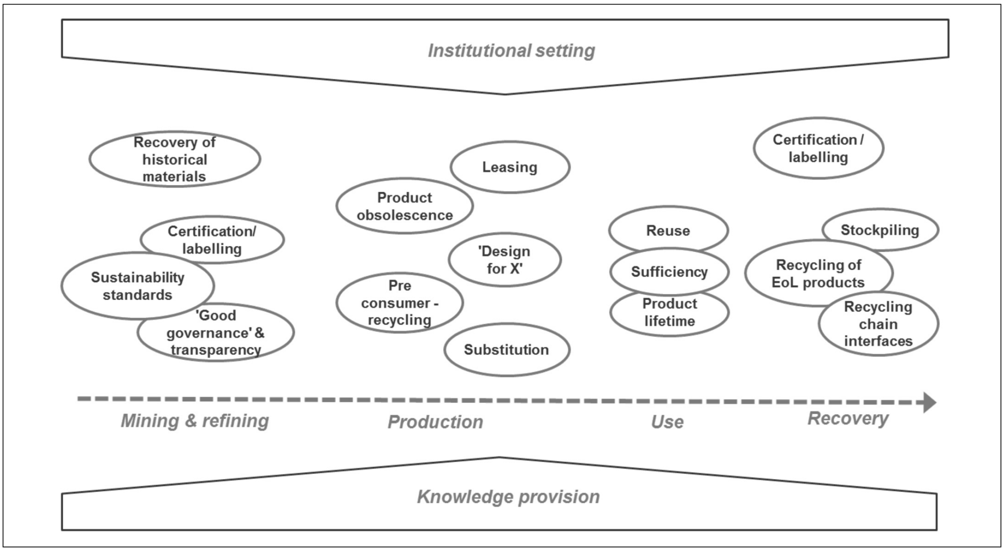


Figure 4. Possible intervention domains for a more sustainable governance of scarce metals according to (Wäger *et al*., 2012).

Regarding substitution, it is important to note that the substitution of a specific material is often expected to lead to performance losses (USGS, 2011), and that it might only be possible with materials that are again expected to be critical (Hagelüken and Meskers, 2010).

Regarding recycling, a recently issued study by UNEP (Graedel *et al.*, 2011, UNEP, 2011) showed that with the exception of some precious metals in particular, for many scarce metals the global average recovery rates from End of Life (EoL) products are typically very low: e.g. for gallium, germanium, indium, osmium, rare earths, tantalum or tellurium they were estimated to amount to less than 1%. For EoL products such as electronic waste, the comparatively higher average recovery rates for precious metals such as gold, palladium or silver of more than 50% might even be too optimistic because of inadequate sorting and pre-processing (Chancerel *et al.*, 2009). This points to the importance of increasing the efficiencies along the entire life cycle, including every step of the recycling chain (collection, sorting, dismantling, pre-processing and materials recovery) (Hagelüken and Meskers, 2010; Wäger *et al.*, 2011a). In this regard, Design for Recycling and Design for Disassembly strategies play an important role. Design for Recycling is particularly challenging for ICT products and components, as they depend on many different scarce metals in complex combinations, from which not all metals might be efficiently recovered for thermodynamic reasons (Reuter *et al.*, 2005; Reuter, 2011).

Regarding the environmental impacts of production, it is expected that primary production is typically associated with higher environmental impacts than secondary production. Significantly lower environmental impacts of secondary production of precious metals such as gold and palladium have been confirmed by a life cycle assessment of the Swiss WEEE Collection and Recycling systems (Wäger *et al.*, 2011b). How far this will also be true for the recovery of scarce metals such as indium or rare earths from EoL products will have to be further investigated, as complex recycling processes may be required for these metals.

Conclusions and outlook

For a more sustainable governance of scarce metals, interventions on different societal levels (consumers, companies, states, and international community) involving many different stakeholders at multiple points along the scarce metals life cycle will be necessary. In view of effective and efficient interventions, significant gaps in the levels of knowledge provision (dynamic stock and flow data, (eco-) efficient processes, substitution) and the institutional settings (programmes and policies, law improvement and enforcement, internalisation of external costs) still have to be overcome.

ICTs both create a demand for scarce metals from primary resources and have the potential to enable a more sustainable governance of scarce metals. The extent of scarce metals *demand* from primary resources will not least depend on progress in the development of new materials and technologies based on alternative, less critical materials. The role of ICTs as an *enabler of sustainable governance of scarce metals* could *inter alia* consist in allowing for sophisticated simulations of possible future demand and supply configurations (Knoeri *et al.*, 2011), providing materials-related life cycle data for primary and secondary supply chain evaluation and certification (ecoinvent Centre, 2009), and managing as well as monitoring ever more sophisticated recovery processes required for increasingly complex EoL products.

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