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Towards a More Sustainable Use of Scarce Metals

A Review of Intervention Options along the Metals Life Cycle

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With the increasing use of scarce metals, new challenges arise. How can we secure a more sustainable use? Intervention options are diverse. In view of reducing action contingency, specific intervention profiles for scarce metals or scarce metals families will have to be developed.

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Abstract
In the past few decades, geochemically scarce metals have become increasingly relevant for emerging technologies in domains such as energy supply and storage, information and communication, lighting or transportation, which are regarded as cornerstones in the transition towards a sustainable post-fossil society. Accordingly, the supply risks of scarce metals and possible interventions towards their more sustainable use have been subject to an intense debate in recent studies. In this article, we integrate proposed intervention options into a generic life cycle framework, taking into account issues related to knowledge provision and to the institutional setting. As a result, we obtain a landscape of intervention fields that will have to be further specified to more specific intervention profiles for scarce metals or metals families. The envisioned profiles are expected to have the potential to reduce action contingency and to contribute to meeting the sustainability claims often associated with emerging technologies.

Keywords
critical metals, life cycle management, non-renewable resources, recovery, resource efficiency, substitution

Supply Risks of Scarce Metals

In the past few decades, geochemically scarce metals[1] have become increasingly relevant for emerging technologies in domains such as information and communication (e. g., high performance microchips/microcapacitors), lighting (e. g., light emitting diodes [LED], glass fiber cables), (clean) energy supply (e. g., thin film photovoltaics, permanent magnets), energy storage (e. g., accumulators), or transportation (e. g., electric motors/permanent magnets) (see table).

Many of these technologies are expected to play a significant role in the transition towards a sustainable post-fossil society (Morley 2008, Angerer et al. 2009, Bauer et al. 2011). In this context, a public debate has arisen over whether the supply of scarce metals is secured in the short-, medium and long-term perspective. As a reaction, various studies evaluating the risks associated with scarce metals supply and the impacts of supply disruptions on economies, sectors and technologies have been published recently. They show that the supply of scarce metals is a multi-factorial issue (NRC 2008, EC 2010, Wäger et al. 2010) and depends on the following types of factors: geological (Skinner 1979), technological (Reuter et al. 2005, Hagelüken and Meskers 2010), (geo-) political (Reller et al. 2009, Corfield 2010, Kim 2010), economic (Huy 2007, MacLean et al. 2010), environmental (Mudd 2007, Norgate et al. 2007, Giurco et al. 2010), and social (Bleischwitz et al. 2012). To give an example, in 2011 more than 95 percent of the world's annual primary rare earth element (REE)[2] production

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TABLE: Examples for the use of scarce metals in emerging technologies of selected domains (Angerer et al. 2009, Bauer et al. 2011).

domain	emerging technology	scarce metals required
(clean) energy supply	■ thin film photovoltaics	silver (Ag), gallium (Ga), indium (In), tellurium (Te)
	■ wind turbines	dysprosium (Dy), neodymium (Nd), praseodymium (Pr)
energy storage	■ lithium ion accumulators	cobalt (Co), lithium (Li)
information and communication	■ flat screens	indium (In)
	■ glass fiber cables	germanium (Ge), erbium (Er)
	■ high performance microchips	arsenic (As), gallium (Ga)
	■ microcapacitors	silver (Ag), niobium (Nb), palladium (Pd), antimony (Sb), tin (Sn), tantalum (Ta)
lighting	■ light emitting diodes (LED)	gallium (Ga), indium (In)
	■ fluorescent lighting	europium (Eu), terbium (Tb), yttrium (Y)
transportation	■ electrical motors	dysprosium (Dy), neodymium (Nd), praseodymium (Pr)

originated from China, a country whose export restrictions have recently raised concern about supply shortages and have temporarily led to a dramatic increase in REE prices (Corfield 2010, Schüler et al. 2011, USGS 2012).

The evaluation criteria applied in the studies differ in their scope. Recent studies (e.g., NRC 2008, EC 2010, Bauer et al. 2011, Nassar et al. 2012) often refer to "criticality". According to the definition of the ad hoc working group of the European Commission (EC), a material is to be considered critical when the supply risk and the potential impacts of a supply disruption are higher than those for most other raw materials (EC 2010). Criticality is a relative concept. It seeks to capture both the supply risks (e.g., physical disruptions, market imbalances, governmental interventions) and the vulnerability of a system to a potential supply disruption in the form of, e.g., production delays or underachievement of societal goals (Erdmann and Graedel 2011).

The criticality of a mineral raw material can be graphically represented as a "criticality matrix", in which the vertical axis reflects importance in use and the horizontal axis availability (NRC 2008). Recently, Graedel et al. (2012) have extended the criticality matrix to a criticality space by introducing an additional axis that allows one to quantitatively include environmental pressures associated with the production of metals (see also Wäger 2011, Wittmer et al. 2011 a, b) as part of criticality assessment.

According to Erdmann and Graedel (2011), the elements most frequently identified as critical are indium (In), niobium (Nb), platinum (Pt), ruthenium (Ru), rhodium (Rh), REE, and tungsten (W). Further frequently listed scarce metals are antimony (Sb), beryllium (Be), cobalt (Co), gallium (Ga), germanium (Ge), lithium (Li), the three remaining platinum group metals (PGM) iridium (Ir), osmium (Os), palladium (Pd), and tin (Sn).[3] Still, there are important limitations to a generalisability of such results, amongst others (Erdmann and Graedel 2011):

- Criticality assessments are based on a pre-selection of raw materials which could potentially be critical.
- The temporal focus of criticality assessments differs.
- Criticality assessments are always made from the perspective of a particular system (e.g., company, sector, country, global society); because different systems are exposed to different supply risks, and the impacts of supply disruptions will differ from system to system, different reference systems will generally reveal a different criticality, even when the analytical approach is similar or identical.

If scarce metals are applied in technologies supposed to support a transition towards a more sustainable society, then their supply likewise has to comply with principles of sustainable development: the preservation of natural resources, the minimisation of adverse environmental and social impacts along the metals life cycle, as well as the robustness/resilience of the supply system against changing socio-technical boundary conditions. Transforming existing scarce metals life cycles into more sustainable ones requires interventions into socio-technical systems ranging from specific technological optimisations to the adaptation of behaviour and lifestyles (see, e.g., Bleischwitz and Bringezu 2008, NRC 2008, Buchert et al. 2009, Achzet et al. 2010, EC 2010, Faulstich et al. 2010, Hagelüken and Meskers 2010, MacLean et al. 2010, Wäger et al. 2010, Erdmann and Graedel 2011, Schüler et al. 2011, Wittmer et al. 2011 b).

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1 A metal is "geochemically scarce" when it occurs at an average concentration in the earth's crust below 0.01 weight percent (Skinner 1979).

2 As defined by the International Union of Pure and Applied Chemistry (IUPAC), the REE or rare earth elements are 17 chemical elements in the periodic table, specifically scandium (Sc), yttrium (Y) and the 15 lanthanoids lanthanum (La), cerium (Ce), praseodymium (Pr), neodymium (Nd), promethium (Pm), samarium (Sm) europium (Eu), gadolinium (Gd), terbium (Tb), dysprosium (Dy), holmium (Ho), erbium (Er), thulium (Tm), ytterbium (Yb), lutetium (Lu).

3 Other scarce metals such as gold (Au), silver (Ag) or tantalum (Ta) have a lower designation rate or were insufficiently covered by the studies. Arsenic (As), rubidium (Rb), molybdenum (Mo), cadmium (Cd), tellurium (Te), caesium (Cs), hafnium (Hf), rhenium (Re), mercury (Hg), thallium (Ti), lead (Pb), bismuth (Bi) are also frequently listed as scarce metals.

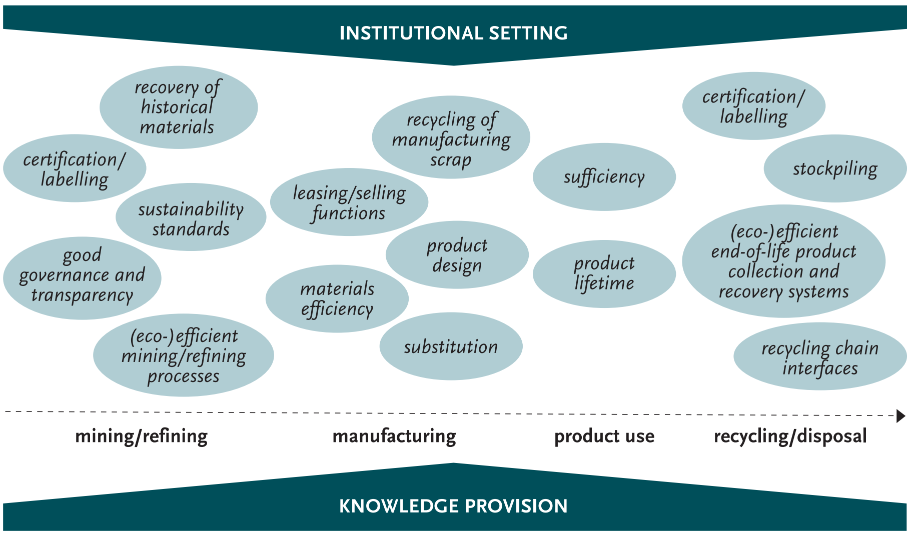

FIGURE: Possible intervention fields for a more sustainable use of scarce metals. The order of the intervention fields within a life cycle phase (mining/refining, manufacturing, product use, recycling/disposal) does not imply any priority.

In the following, we will give an overview of interventions proposed in current studies by integrating them into a generic life cycle framework (including mining and refining, manufacturing, product use, and recycling/disposal), while also taking into account supporting measures related to (cross-cutting) knowledge provision issues and the institutional setting. The resulting intervention fields along the scarce metals life cycle are illustrated in the figure and discussed in detail in three sections below.

Intervention Options

Possible Interventions along the Scarce Metals Life Cycle

Mining and Refining

Several studies address the necessity of increasing the efficiency of extraction and refining processes (see, e.g., NRC 2008, EC 2010). For instance, MacLean et al. (2010) propose improving mining practices in order to reduce the amount of waste to be handled and treated, performing more ore breakage in the blasting stage prior to crushing and grinding, utilising more energy-efficient grinding technologies, using alternative processing routes such as in situ leaching, increasingly using renewable energy technologies, and improving treatment and reuse of resources like water, as well as dry processing. Another intervention proposed is the recovery of historical stocks contained in unmined parts of ore bodies, tailings, slags or landfills (Faulstich et al. 2010, Hagelüken and Meskers 2010).

In recent years, the issues of good governance and transparency have been brought to the fore inter alia by the *Extractive Industry Transparency Initiative (EITI)* and the *Publish What You Pay Initiative (PWYP)* (see, e.g., Schieritz 2009). Likewise, the ad hoc working group of the EC (2010) recommends specific policy actions aimed at promoting good governance, capacity-building and transparency regarding extractive industries in developing countries. In parallel, various steps towards more sustainable exploration and extraction have been undertaken amongst others by the International Council on Mining and Metals (ICMM) (Fonseca 2010).

Certification of raw materials and their supply chains, which allows purchasers to selectively buy raw materials mined under more sustainable conditions (Searchinger 2009), has recently become an issue for conflict minerals, i.e., minerals mined under conditions of armed conflicts and human rights abuses. This especially pertains to tantalum, tin and tungsten which are produced from columbite-tantalite (coltan), cassiterite and wolframite extracted in the Democratic Republic of the Congo. The German Federal Institute for Geosciences and Natural Resources (BGR) in cooperation with authorities in Rwanda and the Democratic Republic of the Congo have initiated pilot projects for certified trading chains (BGR 2012b). In particular, the BGR has developed a method for identifying the mineralogical fingerprint [4] of tantalum ores.

Manufacturing

Various studies address substitution and increased materials efficiency as intervention options (see, e.g., EC 2010, Faulstich et al. 2010). Regarding substitution, two types are distinguished: first, a material substitution of less-critical metals for critical ones, which often cannot be achieved without negative impacts on the functionality of the respective product; second, functional substitution, i.e., the substitution of a product or technology by another that fulfils the same function (Ziemann and Schebek 2010). Issues raised here are whether a specific function is really needed, and how much performance is actually required for a specific application. Regarding materials efficiency, huge potentials seem to be yet untapped (Dobbs et al. 2011). However, the existence of possible trade-offs between less material use per product unit and rebound effects in the use phase (Madlener and Alcott 2011) or lower recovery rates through lower scarce metals concentrations in end-of-life (EoL) products (see, e.g., Johnson 2007) will have to be taken into account.

Product design is considered to play a key role to enhance substitution, materials efficiency, product and component reuse as well as materials recovery (MacLean et al. 2010, Reuter and Van Schaik 2008). With regard to materials recovery, it will be particu-

4 The Analytical Fingerprint (AFP) method aims to identify the origin of metal ore concentrates by comparing their mineralogical and geochemical characteristic features to samples of known provenance that are stored in an AFP reference database (BGR 2012a).

larly important to consider the physics and chemistry of sorting and pre-processing, and the thermodynamics of high-temperature processing and resource recovery (Reuter and Van Schaik 2012). Especially for complex EoL products such as Waste Electrical and Electronic Equipment (WEEE), the authors of a forthcoming UNEP report advocate a product-centric view that allows improving product recycling in its entirety instead of optimising the recovery of few metals at the expense of other metals in the input stream (UNEP forthcoming).

Besides product design, effectively closing product cycles will require appropriate life cycle structures, which amongst others ensure product traceability. More fundamental approaches include changes in the business model, e.g., leasing of products or selling functions instead of products (MacLean et al. 2010).

Compared to the recycling of EoL products, the efficiency of recycling of manufacturing scrap is usually higher due to the greater awareness of the stakeholders involved, economic recycling incentives, transparent and professional handling, rather homogeneous and unpolluted scrap fractions, and fewer change of ownership and location of use (UNEP 2011). Although manufacturing scrap recycling is common practice today, there still is room for improvement, e.g., in magnet manufacturing, where an estimated 30 percent of magnetic material is lost during the machining process (Bauer et al. 2011).

Product Use

In the product use phase, possible interventions towards a more sustainable use of scarce metals include measures related to product lifetime, e.g., improving material and functional durability, which is linked to issues of planned obsolescence[5] (cf. Forge 2007, Guiltinan 2009), or supporting product (and component) reuse. However, it will have to be considered that from an environmental perspective, increasing product lifetime is not in any case preferable, as has been demonstrated for refrigeration equipment (Cooper 2005). This and other issues, such as the dependency of metals in use on wealth and other socio-economic factors (Graedel and Cao 2010) or possible rebound effects related to products and services based on scarce metals applications (cf. Madlener and Alcott 2011) illustrate how complex this field of demand-related interventions is, and that there is no one solution that fits all cases. Still, it will probably be hard to achieve sustainable use of scarce metals without changing our consumption patterns, especially given an ever-increasing world population with growing demands for consumer goods in emerging economies. In this respect, sufficiency strategies should gain increasing importance in addition to efficiency and consistency (the adaptation of material flows induced by humans to natural flows) strategies. It strikes us that the studies analysed hardly elaborate on the former aspect.

EoL Product Recycling and Disposal

For many scarce metals, recovery rates from EoL products are very low (Graedel et al. 2011, UNEP 2011): for instance, for gallium, germanium, indium, osmium, REE, tantalum or tellurium, they were estimated to amount to less than one percent.[6] Accordingly, several studies prominently address the gradual restructuring of open systems into closed ones by implementing (eco-)efficient collection and recovery systems for EoL products (Schüler et al. 2011, NRC 2008). Some prerequisites for such a restructuring are: understanding the fundamental principles and interactions within product recycling systems; applying a comprehensive, global life cycle perspective to scarce metals recovery treating mining and recycling as coevolving systems; establishing an appropriate life cycle structure, including the active cooperation of citizens supported by legislation and marketing efforts; optimising interfaces along the recycling chain in order to avoid recovery inefficiencies (EC 2010, Hagelüken and Meskers 2010, Mac Lean et al. 2010). For the treatment of WEEE in developing countries, the “best-of-two worlds approach” has been proposed seeking technical and logistical integration of “best” pre-processing in developing countries to manually dismantle e-waste and “best” end-processing to treat hazardous and complex fractions in international state-of-the-art end-processing facilities (Wang et al. 2012).

Besides other issues, the dissipative[7] application of scarce metals (Buchert et al. 2009) and their non-functional recycling[8] (Chancerel and Rotter 2009, UNEP 2011) will have to be addressed. Possible mitigation strategies for non-functional recycling might, e.g., consist in an improved (manual) separation of components with particularly high scarce metals concentrations, such as magnets in hard disks (REE) (Schüler et al. 2011) or printed wiring boards (gold, silver, palladium, tantalum) (Oguchi et al. 2011, Blaser et al. 2012), prior to their further treatment. Depending on the availability of further treatment processes, the material then might either be temporarily stockpiled, as proposed, e.g., for flat panel displays (Böni and Widmer 2011), or reused, as proposed for scarce metals with expected complex, energy intensive recycling processes, such as REE (Schüler et al. 2011).

Nevertheless, it has to be kept in mind that there are inevitable trade-offs hampering the recovery of different scarce metals and/or base metals, and, even further, between valuable materials recovery and hazardous substance disposal. Therefore, appropriate recovery system description and optimisation tools (see, e.g., Reuter 2011) are required.

Recently, it has been proposed to develop and implement a certification procedure for scarce metals recovered from EoL >

5 Planned obsolescence is a strategy that shortens the usable life of a product to stimulate replacement buying by consumers.
6 This is not the case for the EoL recovery rates of scarce metals with high economic value such as gold, palladium or silver, which were found to exceed 50 percent.
7 By “dissipation” we understand the “dilution” of materials into the technosphere or ecosphere in such a way that their recovery is made difficult or impossible. The “technosphere” includes all objects and associated material flows that have been created by humankind and are under its control (Sterr and Liesegang 2003).
8 Non-functional recycling refers to the incorporation of scarce metals as “tramp” elements or impurities in large magnitude material streams (UNEP 2011).

products (Wäger et al. 2011 a) in analogy to standards governing the use of other (secondary) resources, e. g., biomass (Roundtable on Sustainable Biofuels 2012). Such an approach could provide secondary scarce metals produced according to principles of sustainable development with a comparative advantage. It might also have to address potential health impacts from impurities depending on the further treatment and the final application of the recycled material.

Providing and Integrating Relevant Knowledge

An appropriate knowledge base is a fundamental prerequisite for setting priorities among the possible interventions. While uncertainties will always remain, substantial efforts should be made to close existing knowledge gaps (MacLean et al. 2010, UNEP 2010 b). Such knowledge gaps have been reported, in particular, for the following three domains:

- substitutes for critical metals,
- scarce metals stocks and flows,
- (eco-)efficient technologies and systems.

Substitutes for Critical Metals

Both the ad hoc working group of the EC and the United States (US) Department of Energy (DoE) recommend that substitution should be encouraged, notably by promoting research on material and functional substitutes for critical materials in different applications (Bauer et al. 2011, EC 2010). Increasing the opportunities under the EU's *Framework Programme for Research and Technological Development* (EC 2010) would be an option. Today, substitution is in many cases expected to reduce the performance of a technology, like substituting aluminium and ceramics for tantalum in capacitors (Angerer et al. 2009, USGS 2011), or to shift the problem onto other critical raw materials, like substituting indium tin oxide (ITO) for antimony tin oxide (ATO) or samarium-cobalt magnets for dysprosium magnets (Angerer et al. 2009). These trade-offs need to be considered when decisions about the substitution of metals are made.

Scarce Metals Stocks and Flows

Various studies highlight the need to improve the availability of reliable as well as consistent stock and flow data for scarce metals along with their dissemination (see, e. g., EC 2010, UNEP 2010 b, Bauer et al. 2011). Regarding stocks in the geosphere, the US Geological Survey (USGS 2011) or the Austrian Ministry of Economy, Family and Youth (Weber et al. 2010), to name just two, provide data for a large number of scarce metals. However, inconsistencies and data gaps must be reckoned with due to inter alia differences in calculation methods or limitations in data accessibility (proprietary data) (Tilton and Lagos 2007, Gordon et al. 2007). Moreover, the uncertainties associated with the different figures are usually not analysed and discussed, the same being true for systematic errors (Ziemann et al. 2010). In order to counteract these deficits, the ad hoc working group of the EC proposes to prepare a *European Raw Materials Yearbook* with the involvement of national geological surveys and mining/processing industries (EC 2010). The formation of a sustainable *European Intelligence Network* to facilitate access for the European Union (EU) to the raw materials information sources and to promote collaboration among experts is underway (cf. EC 2012).

Regarding stocks in society, a review of 54 studies has shown that information on in-use metal stocks is reasonably detailed only for five base metals (aluminium, copper, iron, lead, and zinc), whereas it is sparse for 19 metals, and almost non-existent for the remaining ones. According to Chen and Graedel (2012), the anthropogenic cycles of only about a dozen elements, including scarce metals such as indium, cobalt, platinum, palladium or tungsten, are well characterised. As a consequence, for many elements there still seem to be essential knowledge gaps with regard to stocks in "hibernation" in tailings repositories, industrial stockpiles, or in landfills, as well as to in-use lifetimes, international trade, losses to the environment and rates of recycling for almost the entire periodic table of the elements (UNEP 2010 a, b). The same is said about markets for these metals, which lack transparency with regard to prices, contracts and ownership structures, because many of the metals are not traded on stock exchanges such as the London Metals Exchange (UNEP 2010 b).

Hence, according to the United Nations Environment Programme (UNEP) *International Resource Panel,* the analysis of uncertainties surrounding metal stocks in society and the validation of such results should be intensified, the availability of dynamic stock information (i. e., the [possible] development of stocks over a time interval) improved, and indicators for recycling performance provided for informed policy making (UNEP 2010 b, 2011). Such information is particularly relevant, because the extraction volumes of many scarce metals from mineral deposits have significantly increased in recent decades, as Du and Graedel (2011) show for REE, and have, thus, induced a continuous shift towards more metals stocks in the technosphere. Accordingly, recycling is expected to become increasingly important for applications in which scarce metals are used in comparatively large quantities. For those REE with the presently highest global in-use stocks (the "big four" cerium, lanthanum, neodymium, and praseodymium), this appears to be true for metallurgical applications, automobile catalysts, and magnets in wind turbines and automobiles (Du and Graedel 2011). According to Johnson (2007), the concentrations of gold, palladium, and silver in EoL products (mobile phones or personal computers) or their components (printed wiring boards) are higher than those in minimum profitable ore grades.

Regarding the provision of dynamic stock information, first dynamic models have been set up to analyse growth patterns of in-use-stocks, assess the impacts of stock dynamics on future resource availability or to forecast resource demand by linking material stocks with services (MacLean et al. 2010). Reuter and Van Schaik (2008) have developed a global dynamic material flow analysis (MFA) model that interconnects elements and products in technological systems and links them to mining and metallurgy as well as to environmental impacts.

Encouraging Research into Eco-Efficient Systems and Technologies

With regard to (eco-)efficient systems and technologies, the ad hoc working group of the EC advocates, in particular, the promotion of research on mineral extraction from deep deposits, mineral processing, and recycling of technologically challenging products and substances (EC 2010). Similarly, the US National Research Council (NRC) recommends enhancing research on extraction and processing technologies as well as on remanufacturing and recycling technologies (NRC 2008). More specifically, according to Buchert et al. (2009), basic research on metal applications with serious technical recycling problems such as REE and tantalum in dissipative applications should be enhanced, and recycling technologies for specific fields of application (e.g., solar panels or LCD monitors) should be developed and implemented. Reuter (2011) emphasises the importance of providing simulation models that allow designing sustainable recycling systems and can inform product designers, legislators or managers of take-back systems.

The ad hoc working group of the EC suggests supporting research on life cycle assessments (LCA) for raw materials and their products on a "cradle-to-grave" basis (EC 2010). Some steps in this direction have already been made, e.g., for lithium in the context of electric mobility (Notter et al. 2010, Stamp et al. 2012). In a combined MFA and LCA study, Wäger et al. (2011b) have demonstrated the benefits of scarce metals recycling from WEEE compared to primary production taking the case of the scarce metals gold, palladium and silver from printed circuit boards as an example.

Establishing an Appropriate Institutional Setting

One prerequisite for a successful implementation of the interventions proposed above is an appropriate institutional setting. In particular, this would require:

- developing and implementing policies and programmes,
- improving, extending and enforcing legislation,
- providing economic incentives,
- promoting capacity building, international cooperation and transdisciplinarity.

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Open-pit goldmine in Western Australia. In view of a more sustainable use of scarce metals, a better management of our anthropogenic stocks becomes mandatory.

Developing and Implementing Policies and Programmes

Bleischwitz and Bringezu (2007) propose the implementation of a global resource governance system that consists of the following three cornerstones:

- a panel for sustainable resource management with intergovernmental legitimacy that issues recommendations comprising a view of the state of knowledge that is as objective as possible,
- an international agreement with the goal of managing resources sustainably and peacefully, which establishes the two legal principles of a common heritage of humankind and of materials stewardship,
- an international agency for sustainable resource management that would provide data and guarantee the implementation of internationally agreed tasks – e. g., roadmaps and projects for sustainable resource management in developing countries.

Whereas the *International Resource Panel* was established in November 2007 in the UNEP framework,[9] agencies addressing sustainable resource management have thus far been implemented predominantly on a national level.[10]

The ad hoc working group of the EC recommends continuous improvement in the coherence of EU policy with respect to raw materials supply, e. g., by assessing counterproductive dumping and subsidies, and by supporting best practices in the areas of land use planning and the issuance of permits for mineral extraction in order to cope with the increasing competition for different land uses (EC 2010). Buchert et al. (2009) propose an EU critical metals recycling programme that could include the encouragement of research and development activities, the installation of first demonstration plants and special investment programmes including low interest credits to support the design and implementation of large scale recycling plants for critical metals. The proposed international agency for sustainable resource management would be very useful for dealing with these issues since it would harmonise actions and make programmes more effective.

Improving, Extending and Enforcing Legislation

Legislation should establish an appropriate institutional framework for the sustainable use of scarce metals. Although existing legislation already addresses some issues, it should be extended or improved on others. An example of an extension with regard to primary production is the U.S. *Dodd-Frank Wall Street Reform and Consumer Protection Act* of July 21, 2010, with a rule for companies to disclose their use of conflict minerals if those minerals are "necessary to the functionality or production of a product" manufactured by those companies (SEC 2012). The rule, which comes into force on January 1, 2013, addresses the metals gold,

The intervention profiles should be embedded in an overall strategic framework related to the sustainable use of critical metals and other natural resources.

tantalum, tin and tungsten extracted from mineral ores in the Democratic Republic of the Congo or an adjoining country. In a similar spirit, the proposed EC directives (EC 2011 a, b) will push responsible mining and supply chain management.

Regarding secondary materials from EoL recovery, UNEP proposes encouraging high scrap ratios in products as an incentive to increase the EoL recycling rate and to make fabrication processes more efficient (UNEP 2011). According to Hagelüken and Meskers (2010), recycling targets such as those defined in EU directives are meaningful for the recovery of ferrous and base metals (e. g., steel, aluminium, copper or zinc), but not for the recovery of scarce metals, as long as the recycling targets are mass based and collection rates are insufficient. Legislative measures aimed at prioritising reuse above recycling for EoL products may be counterproductive if system boundaries are crossed, e. g., when the reuse takes place in parts of the world with no effective collection and successive treatment schemes for EoL products (Hagelüken and Meskers 2010); whether reuse is favourable would require case-by-case analyses. Thus, it is essential to improve international cooperation on managing the reuse of critical materials existing in components of used products. It should give incentives for companies to get engaged in countries with low recycling capacities (e. g., West Africa, Central Asia). An international covenant as suggested by Wilts and Bleischwitz (2012) could be an appropriate institutional setting; it would organise a platform for recycling companies, automotive electronic and other industries as well as representatives of public policies to guarantee good investment conditions. As an instrument, it would promote a globally extended producer responsibility (EPR) towards materials stewardship and may even help create a common circular economy for mass materials at a regional scale complemented by a second circular economy for critical materials at an international scale (Sinha-Khetriwal et al. 2009, Wilts et al. 2011).

Providing Economic Incentives

An example of economic incentives to increase resource efficiency is the collection of extraction taxes with revenues going into a national raw material fund. This has already been implemented in certain countries like Norway and Chile (Bleischwitz and Bringezu 2008). From a national perspective, such extraction taxes are a meaningful way to promote the sustainable governance of scarce metals, as they increase national public revenues and support intergenerational equity. In addition, they also smooth price volatility and promote incentives for efficiency increases at downstream industries.

9 *www.unep.org/resourcepanel*

10 For a German initiative see Deutsche Rohstoffagentur (DERA): *www.deutsche-rohstoffagentur.de*.

Promoting Capacity Building, International Cooperation and Transdisciplinarity

According to Buchert et al. (2009), technological issues regarding the recycling of critical metals should be comprehensively adopted in existing educational activities as well as know-how and technology transfer; likewise, international cooperation should be accelerated through promoting international recycling conferences, funding of technological implementation programmes in emerging economies and developing countries as well as specific scientific exchange programmes. The NRC (2008) specifically mentions coordination and data exchange among US agencies collecting mineral information. It also suggests identifying and applying training measures to counteract the existing and growing shortage of resource professionals in industry, government and educational institutions. This becomes especially important when considering the recent discussions on installing or restoring mining and processing capacities for REE in the United States and other Western countries, in order to lower import dependencies (see, e. g., Service 2010). MacLean et al. (2010) emphasise that the "challenge of sustainability" most importantly requires a generation of practitioners and analysts with a multi-, inter- and transdisciplinary understanding of a broad set of issues related to economics, engineering, economic geology, ecology, and mathematical modelling, inter alia. This should be complemented by an in-depth understanding of aspects related to consumer behaviour and decision/policy making on different societal levels as well as competencies to integrate knowledge from different disciplines and the societal practice in order to develop robust governance strategies. They also point to the necessity of better informing stakeholders and citizen initiatives. Accordingly, Buchert et al. (2009) propose launching information campaigns and initiatives by the EU and the member states to draw the attention of the public to the importance and value of critical metals. For example, they recommend addressing the issue of used consumer goods that are "hibernating" in households (e. g., mobile phones in drawers) and hence are temporarily unavailable for the recovery of critical metals. Transdisciplinary schemes designed to achieve a more sustainable use of critical metals should however go beyond informing the public and the various societal actors concerned. They should enable mutual learning processes in which experiential knowledge, values, norms and interests are also considered and integrated in knowledge production and the development of solution options for goal oriented decision and policy making (see, e. g., Lang et al. 2012).

Fragmented Landscape and Future Intervention Profiles

Looking at our intervention "landscape" shows that interventions towards a sustainable use of scarce metals may occur at different points in the scarce metals life cycle, which typically are geographically disperse and involve many actors following their specific rationalities in often uncoordinated manners. A transition towards a more sustainable use of scarce metals will have to take into account this fragmented landscape. It may be ultimately necessary to depart from separate, isolated initiatives addressing specific geographical regions and single issues along the scarce metals life cycle. At least in the mid-term, these initiatives should be embedded in a comprehensive, harmonised strategy. Developing and implementing such a strategy which weighs the different intervention options according to their respective efficiency, efficacy and relevance requires materials and product management models and approaches integrating at least parts of the life cycle (e. g., manufacturing with product use and recycling), such as the materials or product stewardship concept.

A goal-oriented prioritisation and combination of the different possible interventions should thereby be based on the life cycle history and the physical properties of the specific scarce metal or scarce metal family (e. g., type of applications, use patterns, actual EoL product recycling rates, actors involved), under consideration of the knowledge available to evaluate their feasibility and effectivity (e. g., availability of substitution options, stocks and flows in society) and the institutional setting (e. g., existing legislation for the collection and treatment of particular EoL product categories, such as WEEE or EoL vehicles). While, according to the life cycle history of PGM, interventions related to recycling should, e. g., focus more on improving the efficiency along the recycling chain than on the already established recovery infrastructure, for REE the necessary recovery infrastructure will first have to be built up. At the same time, the particularly dissipative use of REE might necessitate a higher priority on substitution than for other scarce metals or scarce metals families, given that substitution options are available for the particular materials or functions.

Defining, prioritising and implementing interventions towards a more sustainable use of scarce metals requires one to cope with several uncertainties and obstacles, be it the dynamics of technological, economic or societal developments or the inertia of established structures opposing sustainability transitions in society.

The presented intervention landscape can help to develop specific intervention profiles for scarce metals or scarce metals families based on best available knowledge. The latter profiles should be guided by sustainability principles, developed in a collaborative approach with all relevant actors, and embedded in a strategic framework related to the sustainable use of natural resources in general. Only in this way will it be possible to set priorities adequately, to use synergies and to avoid unwanted trade-offs.

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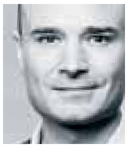

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