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Metal scarcity and sustainability, analyzing the necessity to reduce the extraction of scarce metals

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ABSTRACT

There is debate whether or not further growth of metal extraction from the earth's crust will be sustainable in connection with geologic scarcity. Will future generations possibly face a depletion of specific metals? We study whether, for which metals and to what extent the extraction rate would need to be reduced in order to be sustainable. To do so, we propose an operational definition for the sustainable extraction rate of metals. We have divided 42 metals in 4 groups according to their geologic scarcity. Applying the proposed sustainability definition to the 17 scarcest metals, shows that for almost all considered metals the global consumption of primary resources needs to be reduced to stay within sustainable limits as defined in our analysis. The 8 geologically scarcest metals are antimony, bismuth, boron, copper, gold, molybdenum, rhenium and zinc.

1. Introduction

The extraction and consumption of metals has increased along with economic development. For consumables, communication and infrastructure, a growing range and quantity of metals is essential. Since more than 100 years, global demand of metals increases exponentially (Krausmann et al., 2009). There is debate whether or not further growth of metal extraction from the earth's crust will be sustainable in view of the limited extractable quantities of these metals in the earth's crust. Will technology improvements be able to keep pace with decreasing ore grades and rising energy costs, as has been the case thus far (Skinner, 2001; Bardi, 2013; Bleichwitz, 2010)? In this paper we will investigate whether, for which metals and to what extent, extraction rates need to be reduced to prevent that access to certain metals and their services will become extremely costly for future generations. The result is important for governments, the manufacturing industry and society to focus strategic and economic efforts on the most relevant metals.

This paper does not discuss sustainability with respect to the environmental impacts of mining, processing, manufacturing, using and disposing of materials leading to a possibly harmful dissipation of metals in the environment, and other environmental impacts.

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2. Background

The most influential definition of sustainability was formulated in 1987 by the so-called Brundtland Commission in their report *"Our common future"*: *"Sustainable development is the kind of development that meets the needs of the present without compromising the ability of future generations to meet their own needs"* (World Commission on Environment and Development, 1987). Since then, governments, politicians, scientists and representatives from industry try to make the Brundtland sustainability definition operational. In a period of only two years after the Brundtland sustainability definition was published, about 140 variously modified definitions of sustainable development emerged (Johnston et al., 2007).The same authors estimate that by 2007 some 300 different elaborations of the concept of sustainability and sustainable development existed in the domain of environmental management and associated disciplines. This demonstrates that the Brundtland sustainability definition has been interpreted in many different, even contradictory, ways.

Despite the extensive discussion on sustainability, the concept is hardly or not concretely operationalized for the extraction of primary resources. Several authors (Hansson, 2010; White, 2013; Medveçka and Bangerter, 2007; Goodland, 1995; van den Bergh, 2010) plead for the formulation of an operational definition that can be used at a technical level to enable bringing sustainability into practice. We found only a single concrete approach proposed by Graedel and Klee (2002). This approach assumes that an extraction rate of a metal is sustainable, if a world population of 9 billion people can be provided of sufficient quantity of that metal for a period of 50 years.

How much of a resource is extractable? In technical terms all is extractable. But whether or not extraction at a certain moment in time is economically feasible depends on a combination of factors; the most important being ore grade, depth, location and the willingness to pay for the extracted material (e.g. Tilton and Coulter, 2001; Tilton, 2003; Allwood et al., 2011). It is therefore important to differentiate between reserves and potentially extractable resources. According to the United States Geological Survey (2012b):

- Reserves are that part of the reserve base that could be economically extracted or produced at the time of determination.
- The reserve base is that part of an identified resource that meets specified minimum physical and chemical criteria related to current mining and production practices, including those for grade, quality, thickness, and depth.
- Identified Resources are resources whose location, grade, quality, and quantity are known or estimated from specific geologic evidence. Identified resources include economic, marginally economic, and sub-economic components.
- Resources: A concentration of naturally occurring solid, liquid, or gaseous material in or on the Earth's crust in such form and amount that economic extraction of a commodity from the concentration is currently or potentially feasible.

Part of the world has not yet been intensively explored because of political instability or topographical inaccessibility. Resources may lie beneath a cover of rocks and are so deep that the prospecting technology presently in use cannot yet detect them (Skinner, 2001). Many problems arise when digging deep into the earth due to the increasing temperature and rock pressure. In theory, these resources are available, albeit at considerably higher exploitation costs.

However, it has never been investigated, what fraction of the various metals in the earth crust can be realistically mined. Exploration is expensive and therefore has a relatively short time horizon. Mining companies concentrate exploration on the highest concentrations in a deposit and not on the lower-sub-economic grades. Therefore, an estimate of the extractable global resources has to be made on theoretical grounds. Nevertheless, such estimates are essential to determine the sustainable extraction rate of metals.

The (future) demand for primary resources can be substantially reduced by increasing product life times and the end of life recycling rate of products, both reducing the use of a resource per unit of service delivered (material efficiency), and by substitution. Recycling, material efficiency and substitution will be fostered by rising primary resource prices.

3. Methodology

First, we investigate the concept of scarcity. The lower the ratio between economically extractable metal ores and the (expected) demand for those ores, the higher the geological scarcity. Second, we investigate what fraction of a metal in the earth's crust can be considered as extractable. We subdivide metals according to geological scarcity. We will do this by comparing the extractable global resources of 42 metals and groups of metals (including rare earth elements (REE) and platinum group metals (PGM)) with the 2010 extraction rates provided by USGS (2012a). Third, we formulate an operational definition for the sustainable extraction rate of metals. The operational definition needs to be such that the question *"whether extraction reduction is needed, for which metals, how urgent and to what extent?"* can be answered. We apply our definition for the sustainable extraction rate of metals to the geologically scarcest metals. For each investigated metal, this will clarify whether or not the current extraction rate is sustainable and – if not – to what degree the extraction rate needs to be reduced to be sustainable. Finally, we carry out a sensitivity analysis to investigate the robustness of the results.

4. Scarcity and extractable resources

4.1. Three types of scarcity

After Gunn (2011) there are three types of scarcity:

- Absolute (geologic) scarcity because of depletion of resources.
- Temporary scarcity, because supply cannot match demand due to various causes, e.g. geopolitics, accidents, weather conditions, monopolies, strikes.
- Structural scarcity of companion metals. Companion metals are metals that are contained in ores of major carrier metals and are not produced independently, but become concentrated in the production of the carrier metal at a level that isolation becomes economically justified. They are by-products. The additional revenues of these companion metals may be small, compared to the total operation and do not provide sufficient incentives to expand the extraction of the carrier metal just. Therefore, supply of the companion metals will not necessarily be fostered by rising prices, and remains limited by the extraction rate of the carrier metal.

  According to Gunn:
  - o Major carrier metals are: Cr, Mn, Fe, Al, Mg, Ti, Sn, Ni, Cu, Pb, and Zn.
  - o Co- and by products with a dedicated production and exploitation infrastructure are: Ag, Au and Mo.
  - o All other metals are by-products of carrier metals with little or no dedicated infrastructure.

We investigate geologic scarcity of metals and how metals can be divided in groups of increasing scarcity. Geologic scarcity of a metal depends on how fast the metal is extracted (extraction rate) compared to the availability of (economically) extractable ore in the earth's crust (Gunn, 2011). Scarcity reflects the tension between availability of and demand for resource, and is expressed by the following equation:

$$S_c = \frac{A_v}{E} \quad (1)$$

where S_c—geological scarcity, expressed in the number of remaining years until the depletion of extractable resources; A_v—extractable resources (t). We will use the Global Extractable Resources as defined by the UNEP International Resource Panel (2011a); see Section 4.2 below. E—annual extraction rate (t/year), based on USGS data (USGS, 2012a).

4.2. Extractable global resources (EGR)

What fraction of a metal in the earth's crust can be realistically mined? Table 1 provides enrichment factors of a number of metals in ores compared to the crustal occurrence of those metals. For many of the metals with a low crustal occurrence, enrichment factors of 100–10,000 are normal, whereas for the metals with a higher crustal occurrence, the enrichment factors are much lower: typically 1–100.

According to Steen and Borg (2002), typical differences in extraction costs between extraction from common rocks and from ores are: