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Towards a sustainable use of primary boron. Approach to a sustainable use of primary resources

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ABSTRACT

The sustainable use of raw materials does not only concern the environmental impacts of their production and consumption, but also the intergenerational distribution of access to the raw material or the services provided by that material. From this sustainability perspective, current generations should not deprive future generations from economically accessible ores, but they have the responsibility to assure that a sufficient quantity of enriched deposits of primary materials continues to be available for future generations.

Comparing the extraction rate of different primary materials to their current use, some materials are scarcer than others. Elements like aluminum, magnesium, titanium and vanadium are relatively abundant and cannot be considered critical from a geological point of view. From a point of view of availability for future generations, action is not really urgent for these elements. However, other elements, like antimony, rhenium, gold, zinc and molybdenum are relatively scarce from a geological perspective. The current extraction rate of these elements is not sustainable.

Boron is also a relatively scarce element, comparing the current extraction rate to the geological availability. The accessible ores may be depleted within two hundred years. This may affect future generations negatively in securing services provided by boron. Therefore, we investigated whether the use of primary boron could be reduced to a sustainable level) without losing any of the services currently provided by boron. In this framework we have designed a generally applicable approach for investigating whether and to what extent a combination of substitution, material efficiency and recycling could reduce the use of a primary material to a sustainable level.

1. Introduction

The extraction and consumption of minerals have increased along with economic development. For consumables, communication and infrastructure, a growing range and quantity of minerals is essential. Global demand of minerals increases exponentially. There is debate whether or not further growth of mineral extraction from the earth's crust will be sustainable in view of the limited extractable quantities of these minerals in the earth's crust. Henckens et al. (2014) proposed an operational definition for the sustainable extraction of raw materials: The extraction rate of a material is sustainable, if a world population of 9 billion can be provided with that material for a period of at least 1000 years, assuming that the average per capita consumption level of the material is equally divided over the world's countries. Using this definition a (non-exhaustive) list of 15 geologically scarce materials has been identified. Boron is one of the materials that are relatively scarce from a geological point of view. In this paper we introduce an approach to assess the technical opportunities to (substantially) reduce mining of primary resources, and use this approach to assess whether a sustainable reduction of boron mining would be possible, without losing any of the services currently provided by boron. We first introduce the approach consisting of substitution, material efficiency improvement and/or recycling. This is then applied to boron. We end with discussion and conclusions.

2. Methodology

In an interpretation of the 3R approach (Reduce, Reuse, Recycle), there are three main technical options to reduce the consumption of raw materials:

- Substitution of the material by suitable alternatives in selected applications.

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Table 1
Types of substitution, derived from Ziemann and Schebek (2010).

Substitution type	Explanation
Material substitution	Material A is re-placed by material B
Technological substitution	Reduction of material consumption by technological progress
Functional substitution	Product A is replaced by Product B or service C with the same function
Quality substitution	Product A is replaced by Product A' with a lower, but still sufficient quality
Non-material substitution	A product is replaced by a service with the same function

- Reduced or more efficient use of the material.
- Increased recovery and recycling of the material.

The first step of our methodology is to develop a general approach for determining whether or not a reduction, required for sustainability, of the application of a primary resource is technically feasible by systematically exploring the opportunities and limitations of each of the above reduction options. The objective of the approach is not to determine the optimal mix of substitution, material efficiency and recycling for a particular case, from an economic or ecologic point of view. Nor is it the intention to make a technical or policy blue print of reduction measures. In practice the definitions of the three reduction categories may overlap, and may be combined in one innovation, making it difficult to assign the reduction in primary material use to a single category. Often several reduction scenarios may be possible, applying different mixes of the three measures.

The second step of the methodology is to apply the findings of the first step to determine the reduction potential of boron.

2.1. Substitution

If substitution of a material is possible, this approach may be seen as an interpretation of the first R of the 3R approach. According to Ziemann and Schebek (2010), five types of substitution can be distinguished (Table 1).

Four main factors determine the potential for substitution of a material:

1. The performance of the substitute compared to the original. An important condition for the adequate applicability of a substitute is that the services, provided by the original product, are maintained. For some uses the performance of the substitute may matter less than for other uses. A 100% equal performance compared to the original is not always necessary (i.e., quality substitution). Each specific application will have its own requirements.
2. The environment, health and safety (EHS) properties of the substitute compared to the original. The environment, health and safety properties of the substitute and the original are supposed to encompass all aspects, from cradle to grave, in all stages from the extraction until the end-of-life stage.
3. The financial characteristics of the substitute compared to the original. The (additional) costs of a substitute will depend on its availability, accessibility, and technology. While the effect of prices may be a relative factor, it can be a decisive element for substitutability in practice.
4. The geological availability of the substitute compared to the geological availability of the original. The aim of our investigation of the possible extraction reduction of a material is to conserve scarce materials for future generations. So substitutes should not be less scarce than the original.

Table 2
Overview of possibilities for material efficiency (ME)

ME in production process	Prevention of material loss Process optimization ME in resources purchase Recycling of production waste
ME in products	Light-weight or re-designing products Design for recycling Design for re-use and multi-purpose use Design for longer use, maintenance, repair, remanufacturing
ME during consumption	Longer use and maintenance Reuse Shared use

Table 3
Estimated material efficiency improvement potential range (expert judgment of our own based on literature)

	Estimated material efficiency potential range
ME in production process	1–10%
ME in products	10–50%
ME during consumption(excl. recycling of EoL products	10–50%

Note that an application can be so specific that the material can hardly or not be substituted, e.g., the application of boron as micro nutrient in fruit and seed production. In such an application, material efficiency is the only option to reduce primary boron use. Substitution is not applicable in such case. Recycling only to a limited extent.

2.2. Material efficiency

Material efficiency (or resource productivity) reflects the quantity of services that can be provided by a given amount of a material, e.g., lightweighting of packaging may result in reduced material use to package the same product. Table 2 provides a general overview of possibilities for material efficiency increase.

In this paper, recycling of end-of-life products (consumption waste) will be addressed under recycling. Ordoñez and Rahe (2013) make plausible, that product designers are not in the first place focused on resources conservation, through design for recycling, reuse, maintenance, repair and waste minimization in general. Hence, potential for material efficiency may exist in many products and applications. According to Allwood (2013), generally, lightweight design, product life time extension and more intensive product use are the most effective means to increase material efficiency. Alternatively, Tukker (2004) explored whether Product Services Systems (PSS; e.g., product lease instead of product ownership) may improve material efficiency. His conclusion is that most types of PSS may have some environmental gains, but generally may not drastically improve material efficiency. According to Tukker most can be expected from PSS with the promise of a functional result. For example, international travel can be substituted by videoconferencing. In this case, the functional result is an adequate meeting with effective communication.

How can the potential effect of material efficiency be quantified? Current literature on material efficiency improvement provides mainly examples for specific materials or products, but no meta-studies exist that provide a general overview of potentials. Based on the variety found in the literature, in Table 3, we provide an estimate by ourselves of the order of magnitude of the improvement potential of various types of measures. The efficiency potential indicates the reduction percentage of material use for providing