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Introducing a multi-criteria indicator to better evaluate impacts of rare earth materials production and consumption in life cycle assessment

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Abstract: Life cycle assessment (LCA) is based on the basic principles of sustainable development. LCA method demonstrated its efficiency in providing a systematic environmental assessment approach of a product or a process. The effectiveness and efficiency of these methods lies in the fact that they take into account all life cycle stages of a product, from the extraction of raw materials to end of life treatment (recycling, ...) through an assessment covering different impact categories such as climate change, human health, ecosystems and resources. Existing LCA indicators reflect different issues surrounding resource depletion, creating inconsistency and moreover confusion among LCA practitioners. The evaluation of different life cycle impacts assessment (LCIA) methods done by EC JRC showed that available models did not address the same parameters: short- vs long-term, stock vs backup technology, etc. It also showed that if the correlation between the methods was sufficient for some resources, others such as rare earth elements showed a high level of inconsistency between methods. It was therefore necessary to develop a relevant indicator and harmonized assessment of impacts on resources in LCA. Furthermore, a resource strategy indicator based on the three pillars of sustainable development (economic, environmental and social) would better address wider challenges and making it a more powerful decision making tool. This study aimed to introduce an indicator for evaluating the strategy implications of metal resources for products and to compare different ways of production resulting from extraction of raw materials or recycling, with a special focus on rare earth materials. The indicator would assess the impacts based on a reserve-resource vision [BGS NERC] and the evolution over time and founded over three parameters: technical feasibility, economic viability and political stability (including social and environmental aspects) in representing countries.

Keywords: life cycle assessment (LCA); life cycle impacts assessment (LCIA); resource strategy; rare earth elements

Life cycle assessment (LCA) is based on the basic principles of sustainable development[1,2]. They demonstrate their efficiency in providing a systematic environmental assessment approach of a product or a process. The effectiveness and efficiency of these methods lie in the fact that they take into account all life cycle stages of a product, from the extraction of raw materials to end of life treatment through an assessment covering different impact categories such as climate change, human health, ecosystems and resources. By considering different stages of life cycle of a product and different impact categories, LCA can be used as a decision tool to help the innovation process and avoid the problem of shifting environmental impacts and minimize secondary effects.

In LCA, inputs and outputs as extracted resources and emissions from different stages of life cycle are assessed in terms of impacts called life cycle impact assessment (LCIA). A variety of LCIA methods already exist and at the same time new approaches are emerging due to lack of consistency in providing widely acceptable indicators particularly for impacts associated with resource use. This article, therefore, aimed to analyze the methodological variability of LCIA methods for metals in general and for Rare Earth Elements (REEs) in particular. By doing so it also aimed to discover and suggest new areas of improvement using the case study on REEs.

There is an increasing concern over the environmental impacts of metals. These impacts are either due to toxicity originating from the nature of their chemical composition or due to the use of energy and resources during their life cycle, from mining to final disposal. Impacts associated with the production and consumption of metals are dominated to a greater extent by mining and refining stages as they are very energy intensive processes[3,4]. Raw materials production assessments are then used to model the environmental impacts of different products in which these materials are used. Furthermore one should not forget the indirect impacts of resources and their contribution in reducing global impacts (e.g. REEs and transition to green economy). This paper focused on the LCIA of resource use of REEs.

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1 Resource issues in LCA: the case of rare earths

Existing LCA indicators reflect different issues surrounding resource depletion, creating inconsistency and moreover confusion among LCA practitioners. The evaluation of different LCIA methods was performed by EC JRC[5]. It shows that available models do not address the same parameters: short- vs. long- term, stock vs. backup technology, etc[6]. There are more than 5 impact assessment methods assessing resource use and yet Berger and Finkbeiner[7] demonstrated lack of correlation between them.

The methodological issues of metals depletion and scarcity are treated controversially in LCA framework as mentioned by different authors[8,9]. It was also suggested by EC JRC that there is a need for improvements[5]. Generally the environmental impact associated with the use of non-renewable resources such as mineral metals had been addressed by using four main approaches as categorized by Stewart and Weidema[10]. The first approach is based on the summation of mass and energy relative to the mass and energy of the material extracted. The second is based on use-to-stock ratio[1,11–14]. The third is due to consideration of exergy and entropy impacts[15,16]. Finally it is based on the potential future consequence of resources extraction. The later is considered as end-point analysis. It is based on the fact that an increasing demand on metals tempts their extraction at a high concentration, leaving the future generation to require relatively high effort to extract the same amount. This could result in increasing the cost and then the environmental impact of extraction. There are different approaches to measure the future consequence of mineral extraction such as surplus[17,18], marginal cost[19].

In LCA as a decision tool, special attention has been given to the necessity of a sustainable use of natural resources. In order to elaborate the case for metals in an operational level, one needs to define a measurable indicator. Although the necessity of this measurement is widely agreed on, it seems difficult to recommend any of the existing indicators which are used to measure abiotic resource production and consumption. Furthermore, a resource strategy indicator based on the three pillars of sustainable development will better address wider challenges, making it a more powerful decision making tool.

The rest of the paper was structured as follows. The second section explained some important aspects of REEs. The third presented environmental impacts comparison of REEs with Cu. The methodological inconsistency of different LCIA methods was also analyzed and validated based on their characterizations. Then we introduced briefly resource indicators in LCA and showed corresponding impacts related to REEs. Finally, based on the discussion we introduced a new concept to assess the resource issue. Main conclusions were drawn in the last section.

2 Why REEs?

REEs, despite their name, are relatively abundant in the earth's crust. REEs are the seventeen similar metallic elements from lanthanum to lutetium (lanthanides), plus scandium and yttrium.

Due to their applications, REEs are becoming increasingly important in the transition to a green, low-carbon economy (DEMAND). Their consumption in sectors such as transport, energy and high-tech increases both the demand and price of REEs[20]. They are used in permanent magnets, lamp phosphors, rechargeable NiMH batteries, catalysts among other applications[20–22].

REEs are critical materials with strong Supply risk. More than 90% of the global REEs are produced by one country[23]. The European Commission expert working group (2009–2010) report Defining Critical Raw Materials in the EU published in 2010 identifies REEs as the most critical raw materials group with the highest supply risk[24].

In addition direct and indirect Environmental and Social issues are huge concerns for the extraction and processing of REEs, particularly due to presence of uranium and thorium.

The other major issues are the Recycling of REEs and the balance problem[23]. This problem is more significant on the absence of primary deposits. As the demand for different REEs is not the same and REEs occur in different ratios in ores, the extraction of more scarce elements increase more and more. Hence recycling of REEs even for their suppliers is an important issue.

3 LCIA of REEs

Based on available mining data and mineral processing, LCA of REEs is carried out for a number of mines. As an illustration, Fig. 1 shows the environmental impacts of REEs production from cradle-to-gate (from the extraction of raw materials to production of REEs) compared with Cu. We selected copper since its function is partially similar to REEs and reliable data for copper production is readily available. The impact assessment methods used in this case study is based on ILCD recommendations for life cycle impact assessment in the European context[5].

The main data is based on the Chinese Rare Earth Industry Report 2009. Primary production comes from China, Bayun Obo mine Mongolia. Fuel and energy inputs in the system reflect average Chinese conditions and whenever applicable, site specific conditions were applied, to reflect representative situations.

As can be seen in the figure, for all impact categories except for resource depletion, the ratio of cradle-to-gate