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Enhancing the assessment of critical resource use at the country level with the SCARCE method – Case study of Germany☆

Vanessa Bach*, Natalia Finogenova, Markus Berger, Lisa Winter, Matthias Finkbeiner

Technische Universität Berlin, Chair of Sustainable Engineering, Straße des 17. Juni 135, 10623 Berlin, Germany

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ABSTRACT

The demand for many resources has increased significantly over the last decades due to their growing importance for industrial and technological development. Thus, various methods were developed to assess availability constraints of resources in relation to their vulnerability within countries and/or sectors (criticality). However, these methods display several short-comings. Thus, the aim of the introduced approach is, to enhance the assessment of critical resource use on country level with the SCARCE method, by considering the two dimensions criticality (with the sub dimensions availability and vulnerability) and societal acceptance (with the sub dimensions compliance with social standards and compliance with environmental standards). For five of the 12 introduced categories measuring availability constraints the country specific import mix is used to determine availability constraints of resources individually for the country under consideration. These results can further be compared with global constraints (which are calculated based on global production data) to determine if the country under consideration performs worse or better than the global average. To measure social aspects the categories small scale mining, geopolitical risk and human rights abuse are introduced. Environmental aspects are considered within the categories sensitivity of the local biodiversity, climate change and water scarcity. Additionally, next to metals also fossil fuels are included allowing a direct comparison of both abiotic resources. The SCARCE method is applied for the case study of Germany for which criticality results are presented and their plausibility is validated. It is shown that for Germany tungsten is the raw material showing high risks in all considered dimensions excluding the sub dimension vulnerability. Its high availability constraints are defined by the categories political stability, primary material use and price fluctuations. Further, due to the countries tungsten is imported from (e.g. Bolivia), its compliance with social and environmental standards is low. To enhance the applicability of the SCARCE method, indicator results are provided for 40 resources to assess their availability constraints as well as their compliance with social and environmental standards.

1. Introduction

In the last decades the demand of resources and raw materials rose significantly due to continuing global industrial and technological development. With that also awareness with regard to a sustainable use of resources and raw materials has grown as well, which is reflected in strategies and measures on international as well as national level (e. g. European Commission, 2011, European Commission, 2015; United Nations, 2016). This implies considering availability of resources and raw materials for current and future generations and the vulnerability of countries and/or sectors with regard to critical resources and raw materials (economic dimension) as well as the extraction, processing and use of resources and raw materials in line with ecological and societal considerations (environmental and social dimension). The term "resources" refers to entities, which can be extracted from nature and transferred to the anthroposphere. This includes abiotic and biotic resources, minerals, metals, fossil fuels as well as water, land, and the natural environment (Schneider et al., 2016; Sonderegger et al., 2017).

Methods to determine aspects with regard to resource use have been published manifold in the last years, considerably improving the assessment of resource use. They are addressing the micro (product), meso (company) and macro (company) level.

For the assessment of resource use on product level several

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* Corresponding author.
E-mail address: vanessa.bach@tu-berlin.de (V. Bach).

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approaches exist (e. g. Guinée et al., 1993, Graedel et al., 2012, VDI e.V. (2013), Schneider et al., 2013, Schneider et al., 2015, Dewulf et al., 2015, Bach et al., 2016 and Gemechu et al., 2016). Most of them complement the existing Life Cycle Assessment (LCA) methodology according to ISO 14040/44 (Finkbeiner et al., 2006). These approaches range from considering single aspects (e.g. depletion of abiotic resource (Guinée et al., 1993)) over multiple aspects (e.g. several socio-economic availability constraints (Schneider et al., 2013)) to first approaches with regard to sustainability assessments (e.g. Bach et al., 2016). So far the focus has been on metals and minerals, with only few methodologies also considering biotic resources and raw materials (Oakdene Hollins, 2014; Bach et al., 2017).

For the assessment on company level so far only few approaches exist (e. g. (Duclos et al., 2010; Graedel et al., 2012; VDI Verein Deutscher Ingenieure e.V e.V, 2013; Bensch et al., 2015)), which often consider the same socio-economic limitations to availability as on product level. Additionally to availability, the vulnerability of the considered companies with regard to these materials is taken into account. Assessing the availability of materials within the context of a company's vulnerabilities is referred to as criticality. So far existing methodologies focus on abiotic resources only.

For the assessment of resource use on the country level several methodologies and studies exist (e.g. Eggert et al., 2007, Morley and Eatherley, 2008, Kind, 2011, Knašytė et al., 2012, European Commission, 2014, Bastein and Rietveld, 2015, Hatayama and Tahara, 2015, Glöser-Chahoud et al., 2016, Buchert et al., 2017 and Blengini et al., 2017). For a comprehensive assessment of resource use on the country level in the context of sustainable development, the following dimensions have to be addressed: vulnerability, availability, criticality as well as environmental and social impacts. To determine the dimension vulnerability the aspects *substitutability* followed by *economic importance* and *dependency on imports* are addressed most often. However, more aspects can influence vulnerability as shown by the various aspects addressed in the existing methodologies (Helbig et al., 2016).

As shown in Achzet and Helbig (2013) the most commonly applied indicators for determining the dimension socio-economic availability are *concentration of reserves, production and companies* as well as *by-product dependency, mining capacity* and *demand growth*. The range of considered indicators varies between one (e. g. Buchholz et al., 2012) and eight (e.g. Graedel et al., 2012). However, studies on the product level (e.g. Schneider, 2014, Bach et al., 2016 and Henßler et al., 2016) have shown that more than these eight aspects should be established to reach a comprehensive assessment of socio-economic availability constraints. To calculate the indicator results for the socio-economic dimension, some methodologies use global production data (e. g. Buchholz et al., 2012 and Graedel et al., 2012), while others use a mix of global production and import data, depending on the socio-economic aspect taken into account (e.g. Erdmann et al., 2011, Knašytė et al., 2012, Hatayama and Tahara, 2015, Glöser-Chahoud et al., 2016, Buchert et al., 2017 and Blengini et al., 2017). Whereas some aspects are influenced by the global market and thus are independent from the import mix (e.g. price fluctuations), for other aspects (e.g. political stability) the import structure plays a significant role with regard to the availability of resources and raw materials and thus, should be taken into account. So far import based indicator results are only determined for the categories *concentration of production* and *country risk* (e. g. as done by Erdmann et al., 2011, Knašytė et al., 2012 and Glöser-Chahoud et al., 2016) and no comparison between import based and global results is carried out.

Next to the socio-economic availability, also the physical availability of resources should be addressed. Indicators determining the socio-economic availability consider reserves (identified stocks from which a mineral or metal can be economically extracted as of today (United States Geological Survey, 2015)), whereas the physical availability refers to the long term availability of resources. Thus, all available resource stocks (quantified by the ultimate reserves) are taken into account, assuming that at one point in time they can be extracted as technological development progresses. Existing methodologies focus on socio-economic aspects only, whereas physical aspects are seldom taken into account.

In order to determine the final criticality of raw materials for a country, studies and methodologies either graph the availability and vulnerability dimensions together in a diagram (common two-axis assessment framework as shown by e. g. Eggert et al., 2007, Erdmann et al., 2011, Graedel et al., 2012 and European Commission, 2014) or calculate a single score results by aggregating both dimensions (as shown by e. g. Morley and Eatherley, 2008, Graedel et al., 2012, Knašytė et al., 2012, Bastein and Rietveld, 2015 and Hatayama and Tahara, 2015). So far no common agreement has been reached, which of these is the more favorable approach. However, as shown by Nassar et al. (2012) determining a single score result is challenging as weighting has to be applied, which highly influences the results.

As human beings rely on the environment (and its ecosystem services) it is defined as a resource worthy of protection (European Commission, 2005), and pollution of the environment related to resource use is taken into account in resource use assessment methodologies. Existing methodologies consider environmental implications of resource use either by evaluating pollution of the environment (as done by e.g. Buchert et al., 2017) or by applying the Environmental Performance Index (EPI) (Yale Center for Environmental Law and Policy, 2014) (as done by e.g. Graedel et al., 2012 and European Commission, 2014). When the pollution of the environment is assessed only resource specific impacts (related to resource extraction, processing use and end of life) are taken into account, whereas country specific differences, e.g. different technological standards, are not considered. When EPI is applied only the performance of a country in general and not specific for a resource is taken into account (e. g. processing of aluminum requires more energy and therefore leads to more emissions than steel (Han, 1996)). Further, country specific emissions are determined for the global production mix only, but should also be calculated for the specific import mix of the considered country. Import based results should also be compared to global averages.

Further, when determining resource use in the context of sustainable development also social aspects have to be considered (Jenkins and Yakovleva, 2006; United Nations Environment Programme, UNEP, 2009). Social impacts of a country's resource use are so far taken into account by addressing health impacts applying life cycle impact assessment methods as done by Bensch et al. (2015) or by taken into account aspects addressed in social life cycle assessment as done by Dewulf et al. (2015) and Buchert et al. (2017), e. g violent conflicts, working conditions and corruption of the extracting country. However, country based indicators are determined only for the three countries with the highest global production, therefore neglecting countries with smaller production but possibly higher social violations. Further, social aspects should also be determined based on the import mix and results should be compared to the global average.

Most of the existing methodologies and studies address metals and minerals, with only few ones also taking into account biotic resources and raw materials (e. g. Morley and Eatherley, 2008; Kind, 2011; Knašytė et al., 2012; Oakdene Hollins, 2014) and so far only the publication by (Knašytė et al., 2012)) consider fossil fuels. Assessing availability constraints of biotic and fossil resources and raw materials and comparing them to mineral resources is relevant for a holistic assessment and to identify possible trade-offs (e. g. the use of renewable energy like wind or solar power instead of fossil energy resources leads to a higher demand of specific materials like indium, for which socio-economic availability constraints occur).

Therefore, the aim of the introduced approach is to enhance the assessment of critical resource use at the country level (SCARCE – method) by considering:

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