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Security of supply and scarcity of raw materials

Towards a methodological framework for sustainability assessment

Edited by

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TOWARDS A METHODOLOGICAL FRAMEWORK FOR SUSTAINABILITY ASSESSMENT

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PREMISE

The workshop "Security of supply and scarcity of raw materials: a methodological framework for sustainability assessment" was organized by European Commission, Joint Research Centre, Sustainability Assessment Unit. The workshop took place in Ranco (VA, Italy) on 13-14 November 2012.

This report contains a brief description of the themes debated in the workshop and the questions it aimed to address. It includes the summaries of some presentations held during the meeting and summarizes the main conclusions of the discussions that emerged.

All the presentations of the workshop are available at the following link:

http://lct.jrc.ec.europa.eu/assessment/ResourceSecurity-SecuritySupply

The workshop gathered key experts (policy makers, researchers from academia, consultancy and institutions, industry representatives) to debate the topic of resource analyses in the context of supply chain sustainability assessment, giving special attention to better assessing risks associated with security of supply, scarcity, and others.

The workshop delivered a clear picture of the current state-of-the-art in the mentioned topics and helped to arrive at recommendations for approaches on how to best assess resource scarcity and socio-economic impacts related to raw materials within supply chain sustainability assessment frameworks; particularly in the context of Life Cycle Assessment (LCA).

ACKNOWLEDGMENTS

The workshop "Security of supply and scarcity of raw materials: a methodological framework for sustainability assessment" was organized by European Commission Joint Research Centre, Sustainability Assessment Unit.

We would like to acknowledge contributions made by all participants and their consent to share their knowledge and ideas. We thank all contributing and participating colleagues from the European Commission and the invited external experts for their feedback on the content of this report.

DISCLAIMER

EXECUTIVE SUMMARY

The security of supply of raw materials has become a high-priority theme in the political agenda of the European Union (EU). The European Commission (EC) has started to take action in order to ensure access to resources and avoid supply shortages.

Critical Raw Materials (CRMs) have been identified with the aim of helping to anticipate/prevent supply shortages and focusing efforts and policy actions on materials whose supply interruption would have the most harmful consequences.

Supply chain analysis could be used to detect and signal the use of CRMs in order to enhance the efficiency in their use, facilitate their proper end of life management, speed up their substitution and provide policy makers with proper information. However, so far the mainstream practice for assessing the impact related to resource use in Life Cycle Assessment (LCA) is limited to the depletion potential; the methods recommended at European level by the International Reference Life Cycle Data System (ILCD) don't take into account all socio-economic and geopolitical factors that can constrain access to raw materials.

Recent developments in impact assessment methods are taking into consideration aspects like, e.g., supply concentration, governance of producing countries and material's substitutability, but their inclusion in the LCA framework faces methodological hurdles.

The scope of the JRC workshop "Security of supply and scarcity of raw materials - A methodological framework for sustainability assessment" was to review the methodologies of impact assessment for resources in LCA and the ones for CRMs identification in order to shed light on the supply chain analysis potential in supporting resource policy. Experts from academia, industry, consultancy and institutions have been called to discuss if and how the systematic consideration of CRMs in LCA could provide policy makers and industry with more reliable information on how to manage CRMs more efficiently and how to combine resource security considerations into sustainability assessment.

A broad consensus was expressed amongst the workshop participants in recognizing that current indicators for resources in LCA have strong limitations. Further reflection of the impact assessment methods for resources is needed. In addition to scarcity, other aspects related to resources should be taken into account. LCA should be better defined as a methodology to assess the potential pressures of resources used and emissions, rather than a purely environmental assessment instrument. The socio-economic nature of the existing indicators must be appropriately communicated.

The inclusion of supply risk-related aspects in LCA deserves further investigation and development. It was concluded that LCA has a potential for managing risks related to resources in the context of sustainability assessment.

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1. INTRODUCTION

Prices of raw materials have been growing in the last ten years reaching in some cases (e.g. in summer 2008) unprecedented levels. Though the more recent evolution of prices has changed, displaying a drastic fall in the last two years, prices are expected to rise again in the near future. Manifold reasons are behind this belief. Between them, the pressure on demand caused by the emerging economies and the diffusion of new technologies are important factors.

The concentration of production of some raw materials in few countries and the use of resources as a strategic political tool can also provoke price spikes. Export quotas and other protectionist measures of producing countries have given rise to political concern in the EU and in countries which rely to a large extent on the import of raw materials.

For these reasons many governments have produced studies identifying the raw materials that are subject to a relatively higher risk (Critical Raw Materials, CRMs), and many policy initiatives have been promoted for reinforcing resource security.

In sustainability assessment the use of resources is a point at issue since the start. Two main tools are widely implemented for assessing the sustainability of resource use, i.e. Material Flow Analysis (MFA) and Life Cycle Assessment (LCA).

In MFA, analyses are conducted for specific resources and their flows through the economy. In LCA, resources associated with the supply chain of products are compiled in an inventory phase, and indicators related to burdens of their use are then evaluated. Several impact assessment methods exist, having different theoretical approaches. In 2010 European Commission produced recommendations for the use of these impact assessment methods in the LCA practice (EC - European Commission 2011a). None of the methods analysed in that context takes into account the security of supply, and socio-economic factors that can constrain the availability of resources are not explicitly addressed; focus is primarily on indicators related to resource availability in terms of e.g. reserves. Nevertheless, some methods have been recently developed in order to take into account aspects like, e.g. supply concentration, political stability of producing countries and material's substitutability.

The present report illustrates the results of the expert workshop "Security of supply and scarcity of raw materials: a methodological framework for sustainability assessment", organized by European Commission Joint Research Centre, Institute for Environment and Sustainability in November 2012.

The scope of the workshop was to review the methodologies of impact assessment for resources in LCA and the ones for CRMs identification, in order to shed light on the supply chain analysis potential in supporting a resource policy. In particular, it questioned if and how the systematic consideration of CRM in Life Cycle Assessment (LCA) would provide policy makers and industry with more reliable information on how to manage CRMs more efficiently and how to combine resource security strategies with sustainability assessment.

The report introduces the policy context that motivated this workshop in section 2. It then describes the main issues in the context of the resource debate (section 3), research gaps, objectives of the workshop (section 4) and the agenda (section 5). Summaries of the participants' speeches are in sections 6 to 17. Finally, the discussion between the participants is summed up in section 18 and conclusions follow in section 19.

2. POLICY CONTEXT

In 2008, the European Commission launched the Raw Materials Initiative (EC - European Commission 2008a), based on three main pillars: to ensure the access to raw materials on world market at undistorted conditions; to foster sustainable supply of raw materials from European sources and to reduce the EU's consumption of primary raw materials.

These objectives are recalled in the COM(2011)25 "Tackling the challenges in commodity markets and on raw materials", which stresses the role of resource efficiency, recycling and substitution of critical raw materials within the third pillar of the raw materials strategy (EC - European Commission 2011b).

In order to prioritize the policy initiatives in the field of resource security, the EC identified the materials facing the highest supply risk with respect to the whole economy. The study results listed 14 Critical Raw Materials deserving better monitoring and further potential policy actions (EC - European Commission 2010). A revision of this list is foreseen by the first half of 2014.

The topic of resource criticality is also mentioned in the Flagship Initiative "Resource Efficient Europe", which includes the goal of reducing the use of materials through enhancing the efficiency in the resource use (EC - European Commission 2011c). In this context, "measures to take life cycle impacts more into account, to avoid waste, reuse and recycling more, improved research and innovation and other measures to improve market structure" are pointed out as main strategies.

The European Innovation Partnership on Raw Materials (EC - European Commission 2012) has been launched to foster the technological advances for increasing the internal supply of raw materials, substituting the critical ones and improve their recyclability. The objectives of this Partnership include the achievement of up to ten pilot plants for the exploration, extraction and processing, collection and recycling of raw materials; the substitution for at least three key applications of critical and scarce raw materials; the enhancement of efficiency in material use and in prevention, the re-use and recycling of valuable raw materials from waste streams (especially for materials whose production implies high environmental impacts) and a dynamic modelling system linking trends in supply and demand with economically exploitable reserves and a full life cycle analysis.

3. BACKGROUND

The sustainable management of natural resources in societies, as well as their availability and access, are fundamental issues for ensuring the population's wellbeing.

Resources have been the object of investigation for classical economists, which started to explore the theme of resource availability (especially land) with regard to the human use and population growth (Ricardo, 1817; Malthus, 1798). In 1931 the economist Harold Hotelling in his paper "The Economics of Exhaustible Resources" launched a new research field of economy dealing with the management of natural resources by human societies (Hotelling, 1931).

An intense debate on the likelihood of resource depletion emerged in the mid-twentieth century. A well-known example of this concern is the book "Limits to Growth" (Meadows et al., 1972), in which the availability of finite resources was simulated in relation to the projections of exponential growth of population, industrialization, pollution and food production in a mathematical model.

Recurrently in the history, and especially after the colonialism period, also the access to resources and to raw materials has emerged as a policy concern, particularly in countries depending to a large extent on imports.

The use of material resources is therefore depending on the geological availability as well as on the access to them. In this section the security of supply, the resource scarcity and their place in sustainability assessment practice are briefly described.

3.1. SECURITY OF SUPPLY

The increasing trend in the raw materials' prices and the volatility showed during the years 2005-2009 has led governments and companies to worry about the access to material resources.

The competition for the access to resources has intensified since supplier countries like China have become themselves consumers of raw materials and started to retain part of the production and restricting exports.

The economic development of emerging countries and the population growth contributed to increase the demand of raw materials in quantitative terms; at the same time the variety of materials extracted and used has increased. It includes the so-called "technology metals", which have essential properties for the production of high-tech devices and engineering systems applied e.g. in the production of clean energy technologies.

The security of supply of raw materials has instead become a high-priority theme in the political agenda of EU, which has started to take action in order to ensure the access to resources and avoid supply shortages, which would reflect on loss of competitiveness. Moreover, a safe supply of minerals is essential to achieve the goals of the European environmental policy with respect to a low carbon economy, mitigation of climate change and energy efficient society.

The ad hoc working group that compiled the EU study on Critical Raw Materials (EC - European Commission 2010) considered supply risk and economic importance of different materials as the two main variables. Many other criticality assessments have been published in recent years also in the US (CCMI CER and NRC 2008; US Department of Energy 2010), UK (Morley and Eatherley 2008), Germany (Erdmann et al. 2011) and different methodologies for their identification have been proposed (Graedel et al. 2012) and debated (Buijs and Sievers 2011). Some studies have been conducted also at sectorial level, with reference to the energy sector that requires many technology metals, especially in the case of low-carbon technologies (Moss et al. 2011; Moss et al. 2013).

In these studies, the indicators used to assess the materials criticality vary, but they usually take into account different components: geological, economic, technological, social and regulatory, geopolitical. Aspects like the supply concentration, the economic importance of materials, their substitutability and recycling potential are the most commonly included in these assessments.

As outlined in recent studies, criticality assessments have some shortcomings and "should be interpreted with caution if used to guide future policy" (B. Buijs & Sievers, 2011). Their predictive power is in fact restricted to the short-term and they don't take into account the different features of the resource markets.

Besides the recent new interest, resource security itself is a historically recurrent theme (Buijs et al. 2012). The results of a research project on resources (POLINARES, "EU Policy on Natural Resources, http://www.polinares.eu/) showed that past worries about critical raw materials (or materials perceived as insecure) have never led to real supply disruptions, since the economies have been able to face price shocks with substitutions, recycling and enhancement of resource efficiency.

3.2. RESOURCE SCARCITY

The security of supply of raw materials can be linked with their geological abundance and, consequently, with their scarcity. As shown in Wäger et al. (2012) some "geochemically scarce" metals, i.e. having an average concentration in the earth's crust below 0.01 weight per cent (Skinner 1979), have also a more geographically concentrated supply and are more likely to be considered as critical.

The geological availability of mineral resources is taken into account in some methodologies for the identification of CRMs (e.g. Graedel, Bar et al. 2012) while the EU assessment – that considers a time horizon of ten years – dismisses the risk of running out of mineral resources, as it is too unlikely to happen in the short term.

The risk of resource depletion has been debated for a long time and the scientific community still disagrees on whether depletion should be viewed as a real threat.

The "optimistic" perspective on resource depletion points at technological and socio-economic innovation, markets' adjustments, recycling and international trade, as factors that would intervene in preventing the scarcity of materials or mitigating its consequences. The presence of undiscovered reserves – that could become available once more investments in exploration will turn to be economically favourable – is a further argument against the risk of resources' running out.

The non-dissipative use of metals and the high recycling potential could contribute to ease the pressure on reserves, through the use of secondary raw materials. This contribution depends on the capability of recovering scraps, properly managing the products' end-of-life, exploiting the anthropogenic stocks, i.e. the large amounts of raw materials stored in the technosphere, and creating circular economies.

The actual availability of mineral resources (either discovered or undiscovered) is nevertheless difficult to assess, due to the high uncertainties associated to the resource estimates. Physical scarcity differs to a large extent from one material to another, depending on the geological abundance of minerals in the earth's crust, which varies by many orders of magnitude – iron, e.g., is half a billion times more abundant than ruthenium – and the consumption rates (Andersson and Råde 2002) .

A different perspective on resource depletion looks at the population growth and the economic development of emerging countries, which are driving the demand of raw materials to unprecedented levels, as main threats for future resource availability. This concern rises especially

when a principle of ecological and social justice in the use of resources (both between different geographical areas and between present and future generations) is taken into account.

Scarcity of abiotic resources is a matter of concern also for the related environmental impacts. The exploitation of lower grade deposits, in fact, implies higher impacts on ecosystems. As soon as a lower grade of resource becomes available, extraction implies increasing energy consumption, emissions, water requirements, mining waste, bigger impacts on landscape as well as the exploration of ecologically sensitive areas (possibly including the nature conservation areas, explorations in deep sea and in continental shelves).

Therefore, increased scarcity can imply higher costs for environmental protection. These costs are reduced when operating in developing countries, having low governance and poor environmental regulation. At the same time, such conditions favour the rise of conflicts related to the control of natural resources and lead to an increased risk, both for producers and downstream users.

3.3. RESOURCES AND SUSTAINABILITY ASSESSMENT

The extraction, processing and use of resources have many impacts on the environment as well as on the societal sphere.

Concerning non-renewable materials, mining is an energy intensive activity, facing environmental problems that include the release of pollutants in surface and ground water, particulate matter's emission, the soil contamination and production of overburden. Other potential impacts regard the biodiversity loss, landscape damages, and land use changes (MINEO 1999). The extraction of less concentrated reserves leads to an increase of these impacts and higher energy requirements.

The sustainability assessment of supply chains requires the systematic consideration of all these burdens, as well as the evaluation of the social and economic consequences related to the use of resources.

In current sustainability assessment practice, the use of resources is often evaluated through two main tools: Material Flow Analysis (MFA), and Life Cycle Assessment (LCA).

MFA is "the study of physical flows of materials into, through and out of a given system"(OECD 2008). The accounting of material flows in economies or systems allow measuring and monitoring their resource productivity. MFA has a preventive approach, based on the assumption that the use of resources is correlated with the environmental impacts, thus the accounting of materials flows and their systematic reduction can effectively ease the environmental and social burdens related to the resource use. The minimization of the withdrawal of materials from nature and the enhancing of resource efficiency are main strategies for the improvement of sustainability of supply chains and economies.

Life Cycle Assessment (LCA) is an internationally standardised methodology for assessing the impacts of products, both goods and services, along their supply chains. Resources consumed and emissions that are associated with the supply, use, and end-of-life of products are compiled in an inventory phase. These are then further assessed in terms of environmental, health, and resource-related burdens through the use of indicators in an impact assessment.

The European Commission has developed methodological guidance for LCA practice in response to its 2003 Integrated Product Policy Communication, launching the European Platform on LCA and e.g. publishing the International reference Life Cycle Data (ILCD) Handbook series. The aim is to help harmonise the different methodologies used within the LCA communities and to give recommendations for the use of impact assessment methodologies (EC - European Commission 2011a). These developments were reinforced by the Sustainable Consumption and Production/Sustainable Industrial Policy Action Plan (EC - European Commission 2008b). The Resource Efficiency Flagship Initiative (EC - European Commission 2011c) and associated Roadmap

(EC - European Commission 2011d) complements these developments through plans for recommendations for calculating a Product's or Organisation's Environmental Footprint (EC - European Commission 2013) .

Within the impact assessment phase, resources consumed and emissions associated with the products supply chain, use, or end-of-life are assigned to impact categories.

Three so-called "Areas-of-Protection" are generally addressed – environment, health, and resources. These are then assessed in terms of sub-indicators such as for climate change, ecotoxicity, human health cancer effects, and resource depletion, among others. The indicators are calculated from the emissions/resource consumption inventory for each impact category using Characterisation Factors. These Factors are derived from complex models.

Resources are usually accounted for in LCA in the impact category "resource depletion" under the area of protection "natural resources", which takes into account the issue of present resource use on future availability (EC - European Commission 2011a). Resource scarcity is therefore the rationale on which this category is commonly based in current practice, while different methodologies are used in this context.

All of the models used in LCA have an anthropocentric approach, as they focus on the use value for humans, but are based on different theoretical approaches, classification methods and purposes. The ILCD grouped the different methods in four categories: the ones focusing on an inherent property of the resource (e.g. the exergy); the ones measuring scarcity (i.e. the ratio between the amount extracted and the reserve); the methods for water and the methods accounting the future consequence of resource extraction.

The ILCD recommended a method based on resource scarcity, thus accounting the ratio between resource extraction and reserve. None of the endpoint methods that estimate e.g. impacts at the Area-of-Protection level were recommended, since there is no consensus on the proper methodology for assessing the future consequences of the resource use and scarcity.

4. RESEARCH GAPS AND WORKSHOP OBJECTIVES

The use of resources implies many environmental, social and economic consequences that should be considered in the sustainability assessment of supply chains. At the same time, the use of resources is affected by many variables beyond geological availability, i.e. socio-economic and geopolitical factors that can constrain the access to them.

CRMs have been identified with the aim of helping to anticipate/prevent supply shortages and focusing efforts and policy actions on materials whose supply interruption would have the most harmful consequences.

Supply chain analysis could be easily used to detect and signal the use of CRMs in order to enhance the efficiency in their use, facilitate their proper end of life management, speed up their substitution and provide policy makers with proper information.

The main goal of this workshop was to verify if, and how, the sustainability principles and tools can be applied in the context of a resource policy, and in particular to better manage CRMs at a supply chain level.

This objective required to discuss the way resources are addressed in the current LCA practice when assessing product supply chains, to review recent developments and to debate possible enhancements of the resource depletion category (that primarily focuses on scarcity in many assessments) in the light of policy and business concerns in relation to resource security.

The methodologies for the identification of CRMs required also to be reviewed and compared, in order to get a clear picture of the theoretical approaches and the assumptions behind the identification of CRMs and to evaluate if the criticality assessment methodology is suitable to be matched and/or complemented with LCA, as well as how.

The workshop has, hence, been structured in three main sessions, aimed at addressing the following research questions:

SESSION 1: Impact assessment methodologies of resource depletion in LCA

RESEARCH QUESTIONS

- Which should be the scope of life cycle impact assessment methodologies for resource depletion?
- Which are the latest developments in the impact assessment methodologies for resources and how could they be improved?

SESSION 2: Defining criticality: methodological improvement in the identification of Critical Raw Materials

RESEARCH QUESTIONS

- How the methodologies for the identification of CRMs could be enhanced?
- Which are the main rooms for improvement?
- Which variables should be considered for the identification of CRMs?

SESSION 3: Resource security in sustainability assessment

RESEARCH QUESTIONS

- How (and if) supply risk should be included in LCA?
- How to consider the security of supply within the supply chain sustainability assessment?

WORKSHOP AGENDA

13th November (morning)

9.15 Registration of the participants

9.30 **Constantin Ciupagea** (JRC-IES - Head of Unit "Sustainability Assessment") Institutional greetings and welcome from organizing institution

Lucia Mancini and **David Pennington** (JRC-IES) Introduction to the workshop

10.00 **Session 1: IMPACT ASSESSMENT METHODOLOGIES OF RESOURCE DEPLETION IN LCA**

Key speech: **Ester Van der Voet** Leiden University, UNEP Resource Panel

10.30 Coffee break

10.45 Presentations:

Serenella Sala (JRC-IES), Assessing resource depletion in LCA: a review of methods and methodological issues

Tommie Ponsioen (PRé Consultant), The latest developments in impact assessment methodologies for abiotic resource depletion

Laura Schneider (Technische Universität Berlin), Measuring resource scarcity - limited availability despite sufficient reserves

Mohan Yellishetty (Monash University) Abiotic resource depletion and life cycle assessment: where we go from here?

Johannes Drielsma (Euromines), Indicators of resource depletion: views of the mining industries

12.15 Discussion

13.15 Lunch break

13th November (afternoon)

14.30 **Session 2: DEFINING CRITICALITY. METHODOLOGICAL IMPROVEMENTS IN THE IDENTIFICATION OF CRITICAL RAW MATERIALS**

Key speech: **Malwina Nowakowska**, European Commission, DG Enterprise and Industry

15.00 Presentations:

Evangelos Tzimas (JRC-IET), Criticality screening for raw materials in energy technologies

Henrike Sievers (Federal Institute for Geosciences and Natural Resources, Germany)

Paul Telleen (US Department of Energy) Critical Materials Assessment and Early Warning (pre-recorded presentation)

16.00 Coffee break

16.15 Discussion

17.00 Closure

19:30 Social dinner

14th November (morning)

09.30 **Session 3: RESOURCE SECURITY IN SUSTAINABILITY ASSESSMENT**

Key speech: **Luis Tercero Espinoza**, Fraunhofer-ISI

10.00 Presentations:

Marisa Vieira (PRé Consultant), How to include security of resource supply in supply chain sustainability assessments and LCA?

Adrian Chapman (Oakdene Hollins), Uniting materials security with LCA – A wider view on adding value to sustainability

Hans Saveyn (JRC-IPTS) Improving materials resource management through optimized waste prevention, reuse and recycling, with special emphasis on critical materials

11.00 Coffee break

11.15 Discussion

13.00 Lunch break

14th November (Afternoon)

14.00-16.00 Conclusions of the sessions and final remarks

5. CRITICALITY AND ABIOTIC RESOURCE DEPLETION IN LIFE CYCLE ASSESSMENT

Ester van der Voet

Leiden University, Institute of Environmental Sciences CML

Abstract

In Life Cycle Assessment (LCA), abiotic depletion is an impact category without a generally accepted assessment method. Several methods exist next to each other. They differ considerably in their content and scope. This is due to a (hardly acknowledged) difference in perception of the depletion problem and definition of the problem as environmental rather than economic. Even as an environmental problem, abiotic depletion may be detailed further significantly, by distinguishing more than one impact category based on the (physical) characteristics of the resources.

In the present debate on resource availability, three concepts are relevant: depletion, scarcity and criticality. Life Cycle Impact Assessment (LCIA) methods address depletion and, partly, scarcity. The societal causes for scarcity are not included, nor are issues of importance, substitutability and future demand development. It is the question whether these issues should be included in LCA. If they are, they should come back in that part of LCA which deals with values rather than facts: weighting.

Introduction

Scarcity of resources is a concept presently high on the agenda of resource policies all over the world. Methods are being developed to assess resource scarcity, extended to the concept of criticality, both in the EU and outside. In LCA, depletion of resources is one of the impact categories. Generally, a distinction is made between biotic and abiotic resources, with methods for abiotic depletion most developed. In this paper, the focus is on abiotic depletion. An assessment will be made with regard to this impact category: can it be used as a measure for resource criticality, and if not, could and should it be re-shaped to express resource criticality?

Depletion, scarcity and criticality

Three related concepts play a role in this field: depletion, scarcity and criticality. They are related but not identical. In this paper, they are distinguished as follows:

- Depletion of a resource means that its amount present on Earth is being reduced. It refers to geological/natural stocks.
- Scarcity of a resource means that the amount available for use is, or will soon be, insufficient.
- Criticality of a resource means that it is scarce and at the same time essential for the present society.

Various discussions are relevant here and are introduced both in methods to assess criticality and in the LCIA depletion of abiotic resources category.

When talking about elements such as metals, there is no depletion sensu stricto: the abundance of the element on Earth does not change. However, the amount of ores with a certain concentration of metals can get depleted. Fossil fuels can be depleted as such: once used they have been chemically

transformed into other substances. Depletion can be reduced by the re-use of anthropogenic stocks.

The concept of scarcity adds a societal dimension to depletion. It refers not to the absolute amounts but to resources that can be exploited. With the development of new technologies, with rising prices, or with other impediments being taken out of the way, ever lower concentrated or more difficult to access deposits can be mined profitably, and thus can be added to the available resources.

Criticality adds a value judgment to scarcity: a resource is scarce, AND we have a problem with that. Usually it means that it cannot be replaced easily by another resource. It can also be that a rapid rise in demand is expected due to some new expanding application, which cannot (yet) be met by a rise in supply. This, too, can change over time as substitutes are being developed for the resource or for the product or service it is applied in.

Depletion, scarcity and criticality in the LCIA impact category Abiotic Depletion

Although primarily concerned with depletion as defined above, aspects of scarcity are also included in the debate around the LCIA impact category Abiotic resource depletion. Various classifications have been made with regard to abiotic resources, based on their physical characteristics, such as the distinction in deposits (regenerated on geological time scale) funds (regenerated over a human lifetime) and flows (constantly regenerated). Because of these characteristics, they should be treated differently in LCIA.

Most remarkable for this impact category is the difference in problem definition: what should the indicator actually indicate? The opinion is also present in this field that resource depletion is not an environmental problem but an economic problem and therefore should not be included in LCIA at all. At least four different problem definitions can be distinguished:

- The decrease of the resource itself (e.g., Guinée 2002; Hauschild and Wenzel 1998; Lindfors 1995)
- The decrease of the world's useful reserves of energy/exergy (Finnveden 1996; Dewulf et al. 2007; Frischknecht et al. 2008)
- The contribution of mining and extraction processes to other impact categories (e.g. Lindfors 1995; Steen 2006)
- The potential changes in impacts of such processes in the future due to lower quality natural resources (e.g., Müller-Wenk 1998).

Of these four problem definitions, the last two can be put aside since these are covered by the other impact categories in LCA. The second one is indeed a separate problem. However it only covers a specific type of resource, and attempts to generalise it to use energy/exergy as an indicator for depletion of other resources are therefore incomplete. An assessment was made of these methods by JRC (EC - European Commission 2011a). Based on criteria such as relevance, completeness, scientific robustness, applicability and acceptance it was concluded that the ideal method does not exist. Three were considered acceptable to a certain extent: two encompassing ones and one specific for water. This provides a mixed message: on the one hand, including different types of resources is considered valuable, on the other hand, it may also be a good direction to take to distinguish different types of resources and develop impact factors specific for those.

Looking at the first two problem definitions, we see that they refer to Depletion as defined above. Nevertheless, some of them also reflect economic aspects to some extent. The current rate of extraction is included sometimes, to reflect the speed of depletion. Some methods distinguish between economically exploitable resources from reserve base and ultimate amounts present on Earth. No method, however, adds the criticality dimension.

In all, we can conclude that in LCA, abiotic depletion covers depletion and some aspects of scarcity, but not criticality.

Abiotic resource depletion in LCA: the way forward

A next question is, should aspects of scarcity and criticality be included in the LCIA? The answer to this is not straightforward. One the one hand, these issues are clearly relevant and presently dominating the resource agenda, and therefore also relevant to cover in LCA. On the other hand, LCA as a tool is limited to environmental impacts. Expansion of LCA to also cover economic (LCC) and social (sLCA) issues occurs, but this leads to additional methods rather than new impact categories in the environmental assessment.

To integrate criticality fully in the LCA impact category of abiotic depletion seems to be very difficult because of the subjective elements and the rapid changes that may occur. Including aspects of it could be possible.

In all, various directions for development seem to be available.

A first option is to exclude resource depletion from environmental LCA altogether. The argument would be that it can be considered an economic problem rather than an environmental problem. This is an easy option, fitting into the line of acknowledging limitations of the LCA tool.

A second option is to include issues of scarcity and criticality, if possible and feasible, in LCC or sLCA. These issues then have their acknowledged place as societal, not environmental issues, while they still can be linked to the LCA framework. The way forward is not clear – it would require translating issues into monetary terms related to the life cycle, or translating into social terms to be included in sLCA which is even more difficult as sLCA is still in the earliest stages of development.

A third option is to include resource depletion as a physical phenomenon in environmental LCA, as it seems to be done presently, and add the scarcity and criticality aspect in the weighting, as this is the step where values come into the process. All issues of attaching importance then are included in this weighting step. If this road would be travelled, it would be advisable to split the abiotic depletion impact category into several categories. This opens up possibilities to weigh between different depletion impact categories, allowing a statement on their relative importance.

As there are other reasons besides this one to further detail the abiotic depletion impact category, this last option to me seems a valuable direction to take. The distinction then should be based on physical characteristics, relevant for the process of depletion, rather than on economic characteristics of use and utility. Use, utility, importance, substitutability all are aspects that could come out in the weighting between the categories. One can imagine even location specific elements entering the process. This will play a role for resources that are locally provided rather than globally, such as water or basic construction materials. For metals and fossil fuels, the supply – and therefore, the potential depletion problem – is global.

Concluding, the criticality assessment methods and the LCA impact category abiotic depletion are certainly related. They are not identical, and it would be very difficult and probably undesirable to make them so. Even so, the two types of methodologies can benefit by taking a look at each other's procedures and define their respective roles in the process of including resource supply aspects in the assessments.

6. ASSESSING RESOURCE DEPLETION IN LCA: A REVIEW OF METHODS AND METHODOLOGICAL ISSUES

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Abstract

Life cycle assessment (LCA) is increasingly adopted for the appraisal of products as the methodology accounts for environmental impacts of resource use, both biotic and abiotic. Depletion, scarcity and criticality are key issues under discussion both in the LCA community and in the wider resource debate. The LCA community is currently debating how and to which extent the abovementioned aspects should be considered and modelled within LCA. The present contribute explore issues under debate in assessing resources through existing impact assessment methods.

Introduction

Over the years, the future supply of the global economy with minerals, food, water, and energy has drawn increasing political interest. The depletion of abiotic and biotic resources is a fundamental issue for sustainability assessment, entailing and affecting environmental, economic and social aspects. Sustainability concept has been intimately related to resources from its first appearance. One of the fathers of the definition of "sustainability" was Hans Carl von Carlowitz. The concept was founded in forestry and was strictly resource-based and stayed so for centuries (Carlowitz 1713). The concept was developed by foresters because timber had been excessively overused for producing energy in order to support the flourishing mining industries and become a very scarce resource in the process of the industrial revolution and urbanization. Environmental, economic and social aspects were already involved: not only trees had been cut at unsustainable rates for decades without efforts to restore the forests but also the prices for timber rose ever more, which led to bankruptcy and closure of parts of the mining industry., with significant social impacts.

This interplay of environmental, as well as socio economic aspects is still the fundamental basis of any discourse on resource efficiency and on sustainable use of resources, being abiotic or biotic. According to De Haes et al. 1999, natural resources are considered as "those elements that are extracted for human use. They comprise both abiotic resources, such as fossil fuels and mineral ores, and biotic resources, such as wood and fish. They have predominantly a functional value for society."

Two aspects may affect the environmental sustainability of resource use. The first is the occurrence of impacts associated with the scarcity itself (e.g. when the limited presence of a resource is affecting an ecosystem, e.g. water scarcity or an economic system, e.g. risk of supply of a certain resource). The second is related to the environmental profile associated with the extraction of the resource, e.g. environmental impacts associated with mining activities and exploitation. In figure 6.1, the two aspects that need to be assessed are reported. Existing models accounts for scarcity mainly from a socio-economic point of view, whereas environmental implication are mainly dealt with the mining/ exploitation phase.

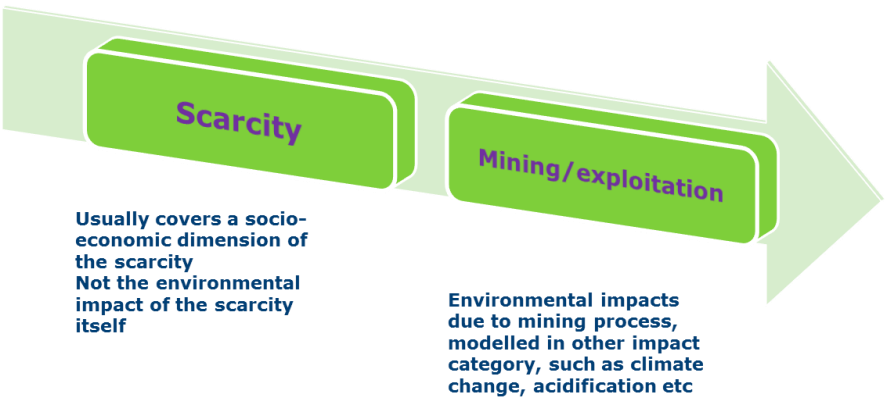

Figure 6.1 A comprehensive assessment of resources should consider two typologies of impacts: those associated with the scarcity itself and those related to the environmental burdens due to mining/ exploitation activities

Therefore, a comprehensive modelling of impacts associated to resource use should discriminate between:

- Environmental dimension and impacts due to scarcity. For abiotic resource, the environmental impact associated to scarcity is related only to those resources that are: part of biogeochemical cycles and/or provide functions in term of ecological niche/habitat. The environmental burden of the other abiotic resources, almost inert in the environment, is therefore associated to their extraction but not to their scarcity. For biotic resources, the environmental dimension associated to scarcity is much more relevant, as those resources represent ecological niche and habitat, as well as provide ecosystem services of different typologies.
- Socio economic dimension and impact due to scarcity. For both biotic and abiotic resource, scarcity may imply significant impact on socio- economic aspects.

Clearly, the crucial question to be addressed in assessing criticality is "to whom the resource is critical?" Indeed, if the shortage in the resource is critical to country, company, sectors, the socio economic implication should be take into account and modelled (e.g. risk of supply, geopolitical risk etc.) whereas different models underpin the assessment if the resource is critical for the environment, namely if there are risk related to scarcity in a bio-geological cycle, and/or risk related to the environmental profile of the resource extracted.

Resource assessment in Life Cycle Impact Assessment

In the last 30 years, a number of indicators for resource depletion have been developed, some including economic aspects related to abiotic and biotic resource consumption. Indicators such as Domestic Material Consumption (DMC), Environmentally-Weighted Material Consumption (EMC), and National Accounts Matrix Extended by Environmental Accounts (NAMEA) seek to quantify environmental pressures from resource consumption in national accounting. The Ecological Footprint (EF), Human Appropriation of Net Primary Production (HANPP), and Land and Ecosystem Accounts (LEAC) pursue a similar goal (cf. EEA 2010; van der Voet et al. 2009).

In the context of Life Cycle Assessment, resources are modelled and handled both at the level of inventory (LCI) and at the level of Life Cycle Impact Assessments (LCIA). Presently, LCIA methods, consider resource depletion in a relatively limited way: use of natural resources is covered in LCIAs mainly as extraction of a resource from the natural environment leads to a decrease in its future availability for human use. Environmental and human health impacts related to extraction or use, such as toxic emissions, are kept as separate environmental impact categories. While any transfer of a resource from the natural environment to the anthroposphere decreases availability in the

former at least temporarily, political and economic factors, as well as technological developments, exert their influence on the resource supply situation.

Current impact assessment methods for resources

Impact assessment methods in LCIA are reported below. This list mainly entails the methods described and evaluated in the analysis done by EC-JRC 2010a/b and compared by Klinglmaier et al 2013:

- Scarcity/mass based: CML (Guinee et al. 2002; van Oers et al. 2002) and EDIP methods (Hauschild and Wenzel 1998)
- Exergy: (Dewulf et al. 2007)
- Surplus energy: Eco-Indicator 99 (Goedkoop and Spriensma 2001) and IMPACT 2002+ (Jolliet et al. 2003)
- Marginal cost: ReCiPe methodology (Goedkoop et al. 2009)
- Willingness-to-pay: EPS 2000 (Steen 1999)
- Distance to target: EcoPoints method (Frischknecht et al. 2008)
- Anthropogenic stock extended Abiotic Depletion Potential (AADP): (Schneider et al. 2011).

Amongst the methods, the comprehensiveness in terms of number of resources modelled is different (Table 6.1). Furthermore, the European Commission recently has been listing a number of critical raw materials (CRM), based on their supply risk and economic importance. Only few of them are modelled by existing methods (table 6.1 and 6.2).

Table 6.1 Coverage of resources in the different methods

	Exergy	AADP	CML 2002	EI99	Ecopoints 2006	EDIP 97	EPS 2000	IMPACT 2002+	ReCiPe 2008
Minerals	57	10	48	12	1	29	67	13	19
Fossil fuels	6		4	4	4	4	3	5	4
Nuclear fuels	1		1		1	1	1	1	1
Biotic	5				1		2	1	0
CRM	0	2	13	1	0	8	28	1	7

Table 6.2 Critical raw materials and number of methods that provide characterization factors (] refers to a resource included in the method recommended by EC-JRC 2011)

CRM	Number of methods covering the resource	CRM	Number of methods covering the resource
Antinomy	4	Indium	2
Beryllium	3	Magnesium	1
Cobalt	4	Niobium	2
Fluospar*	-	Platinum group metals	Platinum 2 Palladium 2
Gallium	2	Rare earths	Yttrium 3
Germanium	2	Tantalum	3
Graphite*	-	Tungsten	4

Relative ranking of the different methods

Besides the differences in comprehensiveness, also the relative ranking of the characterization factors between resource present significant differences. Taking iron as reference resources, and normalizing the different CFs over iron, the relative ranking show difference up to several orders of magnitude (figure 6.2). The comparison shows, moreover, that a similar theoretical basis of impact assessment methods does not correspond to a similar ranking of resources with respect to scarcity/depletion potential. For example, the EDIP 97 and CML 2002 methodologies are mass based, yet show considerable discrepancies in mineral depletion indicators in relation to iron.

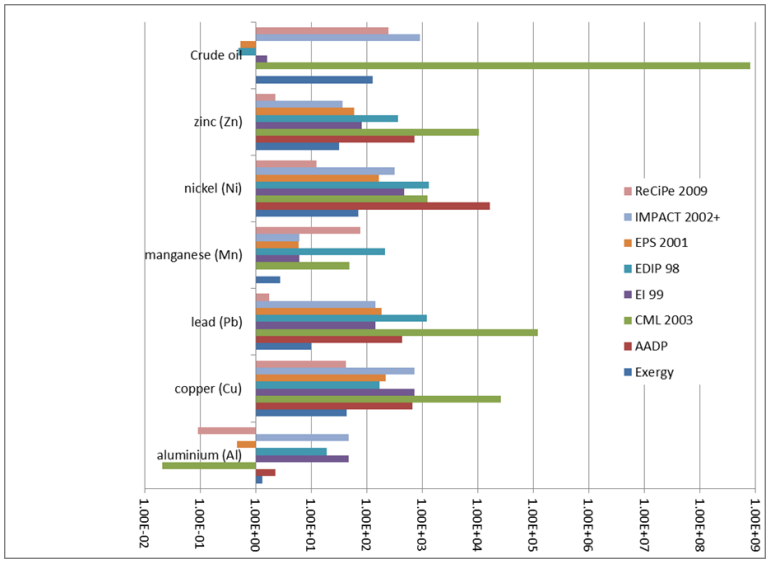

Figure 6.2 Relative ranking of mineral resources, considering iron as reference. The compared methods are those reported in the section of "current impact assessment methods for resources". (Modified from Klinglmeier et al 2013).

One resource's relative importance is thus strongly dependent on the model chosen by the user. A comprehensive and unbiased assessment would therefore necessitate the impracticable task of looking at the currently available range of methods in parallel.

Outlook

The necessity of including natural resources as an area of protection in LCIA has been debated for many years, and the scientific debate is still on-going. The interplay of environmental and socio-economic aspects suggests that resources should be, anyway, part of the impact assessment phase within Life Cycle Sustainability Assessment (LCSA).

Furthermore, the biotic resources, relatively less evaluated by current impact assessment methods, should be more carefully analysed and evaluated in an ecological perspective, namely in light of the carrying capacity concept.

A bidirectional relationship between methodologies for assessing criticality and life cycle assessment could be considered since strategies of resource efficiency could be applied both for reducing environmental burdens, supporting a sustainable choice of substitute materials and boosting economic benefit.

Further research is needed in order to explore: whether criticality should be part of the impact category "resource depletion" and of an area of protection "natural resources"; how to use results of LCA for comparing CRMs or for identifying a potential substitute material - having the best environmental profile-; whether socio-economic implications should be part of the LCA or not; if current LCA indicators and results for resources provide governments and business with the most appropriate information for decision support.

7. THE LATEST DEVELOPMENTS IN IMPACT ASSESSMENT METHODOLOGIES FOR ABIOTIC RESOURCE DEPLETION

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Abstract

The stakeholder consultation carried out within the LC-IMPACT project showed that there is interest for different abiotic resource depletion indicators depending on the time horizon chosen. For a mid-term perspective, the increase in efforts was indicated. The ReCiPe endpoint method follows this approach but was judged in the ILCD Handbook as too immature to be recommended. At midpoint level, a method based on the use to stock concept was chosen. However, this concept cannot be combined with the endpoint concept of future availability and effort needed. We are currently working on the improvement of the ReCiPe endpoint method for abiotic resource depletion, based on the marginal cost increase for different fossil resource types and minerals with three different future production and discounting scenarios. For minerals, we propose a new midpoint indicator. For fossil resources, however, we could not define a constant mid- to endpoint factor. Geopolitical effects are left out of scope.

Introduction

The ILCD Handbook recommendations for LCIA in the European context (EC - European Commission 2011a) concluded that endpoint methods were not mature enough to be recommended. The EU FP7 funded project LC-IMPACT started shortly after to further develop LCIA methods in general. At the start of that project, a stakeholder consultation was organized with 20 participants representing policy, industry and experts (Vieira et al. 2011). Three types of indicators using different time horizons were selected for mineral and two for fossil resource use: 1) the long term focuses on overall availability (depletion = midpoint; not for fossil resources); 2) the midterm (<20 years) focuses on the increase in effort (scarcity = endpoint); and 3) the short term (<5 years) focuses on the availability depending on political factors (criticality).

For the midpoint indicator, there is already a recommendation in the ILCD Handbook (Figure 7.1). However, it is based on the use-to-stock concept, which cannot be combined with the increase in effort concept for the endpoint. Vieira et al. (2012) propose an indicator based on the marginal decrease in ore grade for minerals with the example of copper. This indicator can be used further in the environmental mechanism to an endpoint indicator. Of the evaluated endpoint methods in EC-European Commission (2011b), the ReCiPe surplus cost method (Goedkoop and De Schryver 2009) was selected as interim method. In the LC-IMPACT project, this method has been developed further. This paper shortly describes the proposed method with the example of crude oil.

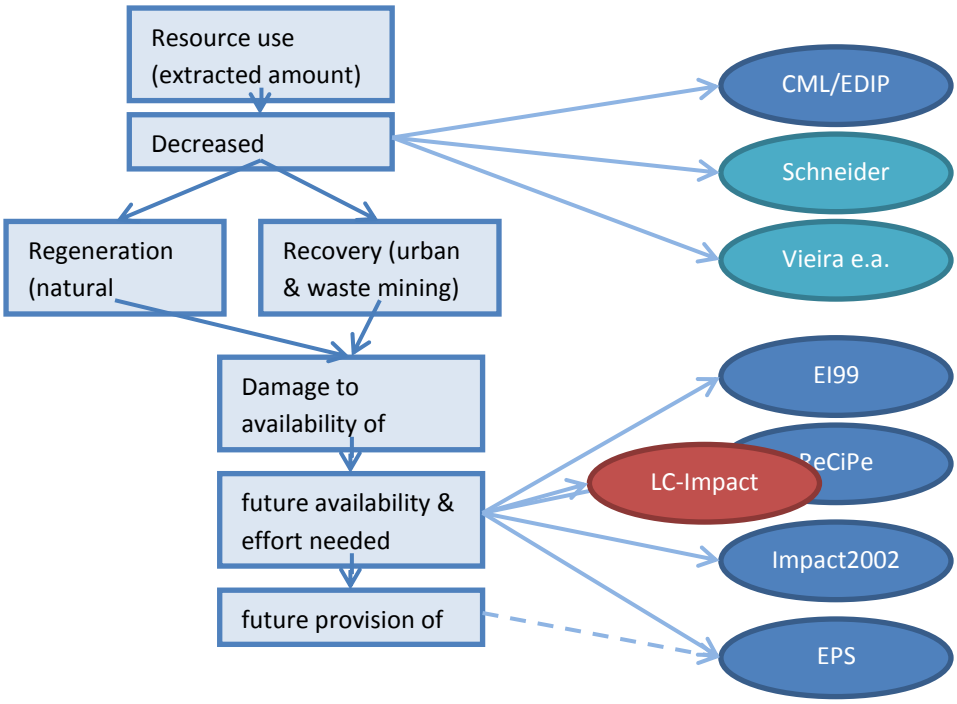

Figure 7.1: Overview of methods for resources (based on EC-JRC-IES, 2011)

Surplus cost as an endpoint method for resources

Surplus cost (SC) is defined here as the global future cost increase due to marginal fossil resource use. The LCI parameter is the mass of crude oil extracted from the natural environment. The first step in our method is to determine the marginal cost increase (MCI). The MCI is the long term average increase in cost after producing a certain amount of resource, based on the concept that first the least costly resources are extracted. The MCI is calculated (in US$ per kg[2]) using cost and resource availability data per production technique in case of crude oil. These data were derived from several International Energy Agency (IEA) reports. Figure 7.2 shows the data for crude oil as an example. A line could be drawn through the graph to get a rough estimate of the MCI. To be more exact, we applied Monte Carlo simulations assuming uniform distributions between the minima and maxima of the cost ranges. This means that we split up the cumulative production per production technique or country into equal amounts and randomly assigned a cost value to each of these amounts between the minima and maxima. Then, the graph is reordered from lowest to highest cost. This way, we simulate smoother transitions to more costly production techniques. By doing this many times, we got a picture of data uncertainty for calculating the MCI (Figure 7.3).

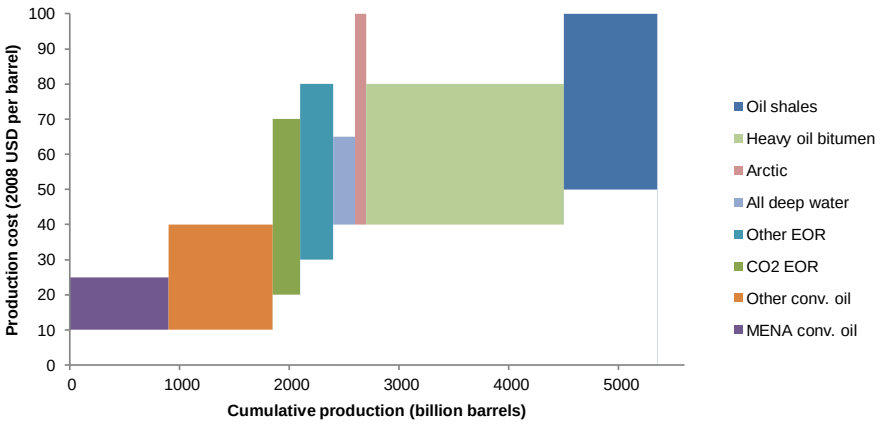

Figure 7.2 Cost-cumulative production curve for crude oil. Legend: EOR - enhanced oil recovery; conv. - conventional; MENA - the Middle East and North Africa region (source: IEA 2010); this figure shows that the exploration costs will increase after the conventional oil is depleted. The method is based on this mechanism.

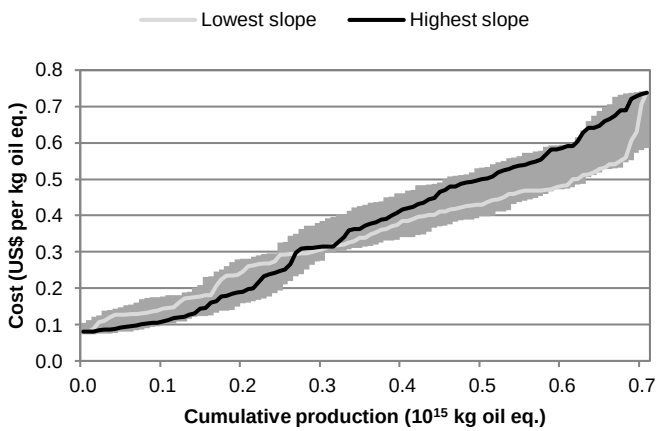

Figure 7.3 Cost-cumulative production curve for crude oil based on Monte Carlo simulation, where the grey area is the range per 50 billion barrels and the slope is the marginal cost increase (cost estimates refer to the year 2008); this calculation has "smoothened" the block shape relationship between costs and production.

To calculate the surplus cost indicator in US$ per kg resource use, the MCI is multiplied by a certain future production volume. In LCA terms, this volume is then the area of protection for fossil resource depletion. More specific, the total amount of resource still available could be chosen as the area of protection. However, this would mean that cost made in the future has the same value to us now as it has in the future. Because not everyone agrees on this, for example because of expected inflation or opportunity cost, we introduced a discount factor in the equation. The surplus cost (SC) is the sum of the cost in all years in the future, and the cost in year t is the MCI multiplied by the annual production (P_t) and a discount factor ($D_t = 1/[1+d]^t$; d is the discount rate): $SC = \Sigma(MCI * P_t * D_t)$.

Because choosing a discount rate and future production scenarios is subjective and seriously influences the results, we calculated the indicators for three different societal perspectives based on Cultural Theory. For each perspective, we chose different discount rates: 15% for the individualist; 3% for the hierarchist; and 0% for the egalitarian. We selected future fossil resource production scenarios from the SRES report (IPCC 2000) and we coupled them to the different perspectives (Figure 7.4). These scenarios are based on demand for fossil resources, which is driven by population growth, economic growth, substitution and technological development. Figure 7.5 shows an overview of the pathway from fossil resource use to the surplus cost indicator.

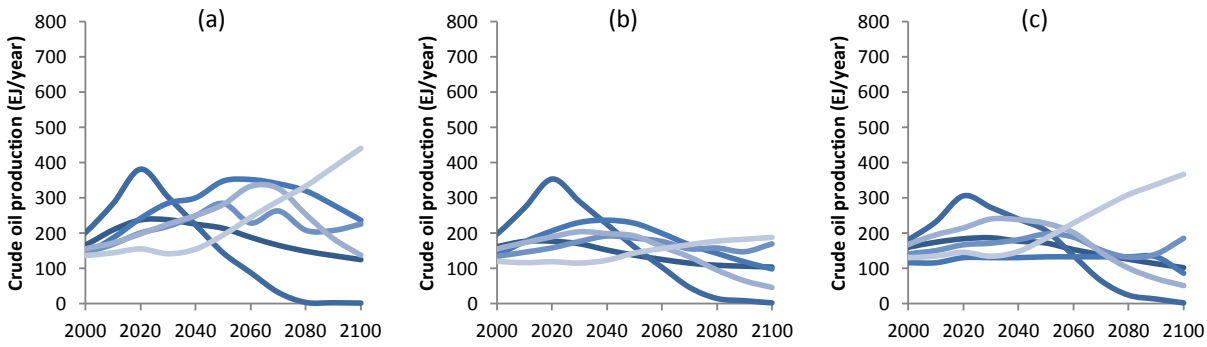

Figure 7.4 Crude oil production scenarios A1 (a), B1 (b), and B2 (c) for all six macro-economic models (source: IPCC, 2000. Emission scenarios. A special report of the IPCC working group III.)

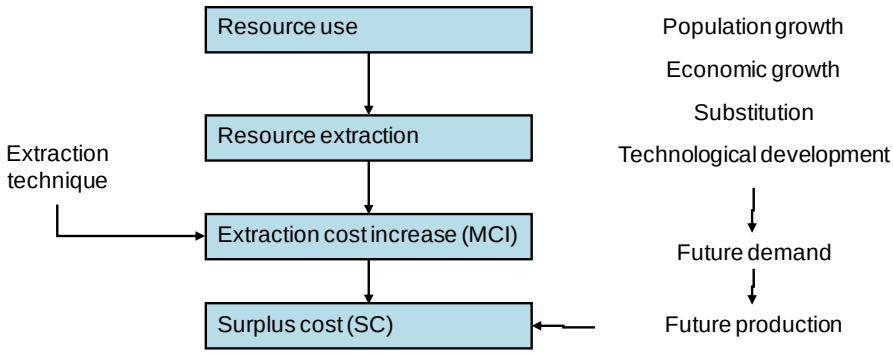

Figure 7.5 Overview of the pathway from fossil resource use to the surplus cost indicator

Discussion

For selecting a midpoint indicator in combination with the surplus cost as endpoint, we need to take into account that there should be a constant mid- to endpoint factor. For fossil resources, such an indicator was not found. For minerals, on the other hand, there is a constant factor. However, this still needs to be worked out.

It is common practice in LCIA to use fixed time frames (e.g. for global warming). However, we chose to use discount factors because the method is based on a monetary indicator, even though this may not be consistent with other impact categories. There is also a large uncertainty factor in the surplus cost method, as future production scenarios may be revised in the future due to new insights in expected substitution and expected technological development.

An important issue to note is that geopolitical effects are left out of scope for the LCIA in LC-IMPACT. The question is if it is desirable, feasible, and if yes, how to include such effects are not yet addressed?

8. MEASURING RESOURCE SCARCITY – LIMITED AVAILABILITY DESPITE SUFFICIENT RESERVES

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Abstract

Global economy depends on resource inputs extracted from the environment and easy access to these resources is often seen as a precondition for economic development. Increasing complexity of supply chains, globalization and the monopolistic control of resources lead to unstable supply situations. Within LCA the use of resources is currently aggregated on a mass or embedded energy basis and evaluated by means of indicators based on stock ratios, additional energy requirement for future production, etc. Other aspects influencing the security of supply are neglected. Thus, the aim of this study is to enable an assessment of resources beyond the geological availability, by including socio-economic indicators and thus to deliver additional decision support.

Introduction

The analysis of resource use and availability is of major importance to secure future resource supply. Within life cycle assessment resource use is currently evaluated by means of indicators primary energy demand (PE International 2010) and abiotic depletion potential (Guinee et al. 2002).

In a previous work (Berger and Finkbeiner 2011) life cycle inventories of 100 resources from the GaBi (PE International 2010) and ecoinvent (Ecoinvent 2010) databases were compiled and analysed by a set of life cycle impact assessment indicators measuring resource consumption, such as abiotic depletion potential (Guinee et al. 2002), EDIP resources (Hauschild and Wenzel 1998), and surplus energy (Goedkoop and Spriensma 2001). Strong linear regressions (R^2 between 0.65 and 0.98) have been identified as all indicators are dominated by the consumption of fossil energy (e.g. some characterization models provide a general characterization factor for fossil fuels that is 'translated' for individual energy carriers based on net calorific value). Thus, resources which are commonly perceived as scarce, like rare earth metals, are not "visible" in the indicator results. Advancements of existing methods have been proposed, e.g. differentiation of ADP into $ADP_{elements}$ and ADP_{fossil} or inclusion of anthropogenic stocks into the assessment (Schneider et al. 2011). However, current life cycle impact assessment indicators deliver no conclusion about the real availability of scarcity of metallic resources for production processes.

Thus, it is not enough to just pay attention to geological reserves. The actual availability of resources depends on a whole set of criteria. From a socio-economic perspective there are many aspects which limit the availability of raw materials beyond geologic scarcity.

Several methods have been proposed for the assessment of additional aspects determining material availability (National Research Council 2008; Rosenau-Tornow et al. 2009; EC - European Commission 2010; Graedel et al. 2012). However, so far an inclusion of these indicators into current Life Cycle Assessment is still missing. Thus, the further development of current approaches seems necessary. Goal of this work is to enhance current resource assessment in connection with LCA by considering supply risks that occur along the supply chain.

Methodology

Based on an exemplary set of aspects (e.g. country concentration, political stability, company concentration, secondary production, demand growth), indictors enabling the quantification of these aspects are determined and related to a target above which scarcity is expected (based upon the ecological scarcity method (Frischknecht et al. 2009; Müller-Wenk 1978)). The inclusion of such "scarcity threshold" enables an assessment based on e.g. company targets and offers the possibility to include an industry perspective.

$$\text{Economic resource scarcity potential} = \prod \left(Max \left\{ \left(\frac{\text{current value}}{\text{threshold}} \right)^2 ;1 \right\} \right) \tag{1}$$

The different aspects can be combined to a single "economic resource scarcity potential" (ESP) by multiplication (see Eq. (1)), enabling a ranking of risk associated with different resources. To avoid the offsetting of critical aspects, values below 1 (<1) are set equal 1 (=1). The following table shows an exemplary set of aspects influencing resource availability and according indicators enabling their quantification.

Table 8.1 Relevant aspects and indicators for assessing economic resource availability

Aspects	**Description**	**Indicator**
Reserves	Geological availability (displaying current production technologies)	Reserve-to-annual production-ratio/ depletion time
Country concentration	Reserve concentration to certain countries	Herfindahl Index (HHI)
Stability	Political and economic stability of producing countries	World Governance Indicators (WGI), scaled
Company concentration	Concentration of extraction activity to certain companies	Herfindahl Index (HHI)
Secondary production	Recycled content of a material	New material content
Trade barriers	Percentage or production underlying trade barriers	%-share of production under trade barriers
Substitution	Lost market due to application of new/other materials	% substituted per year
Companion Metal Fraction	Complex and interconnected production of metal, fixed production volume	% produced as by-product
Anthropogenic reserves	Material availability in anthroposphere	Depletion time (compared to production)
Expected demand growth	Assumed increase of demand in future	% growth of demand per year

In order to illustrate the effects of this approach, comprehensive case studies are accomplished. Several resources are analysed based on the described aspects. Significant parameters and bottlenecks are identified and the results are evaluated and compared to results obtained by means of conventional resource assessment within LCA. Availability of resources differs significantly when economic aspects are taken into account in addition to a geologic availability assessment.

Outlook

The extensive use of resources is associated with many supply risks that have to be assessed to ensure a sustainable development. The proposed method expands life cycle assessment practice towards life cycle sustainability assessment and will support a more comprehensive assessment of resource use and availability. By identifying, quantifying and aggregating different socio-economic aspects, more realistic resource scarcity analyses are promoted.

Several more indicators that are relevant for determining the supply risk associated with individual resources and furthermore, the risks at different stages of the supply chain have to be assessed. However, due to limited data availability, these indicators have not been taken into account yet, but will ideally be included in the further enhancement of the method.

There is still a strong need for harmonizing indicator selection and combination and the development of additional indicators displaying aspects of resource availability.

9. ABIOTIC RESOURCE DEPLETION & LIFE CYCLE ASSESSMENT: WHERE FROM HERE?

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"There are untold millions of iron ore in the Pilbara deposits. I think this is one of the most massive ore bodies in the world. There are mountains of ore there … it is just staggering. It is like trying to calculate how much air there is." Tom Price, Vice-President of Kaiser Corporation (1960's) (pp. 16) (Sykes, 1995)

Abstract

Life cycle assessment (LCA) is a major method and tool for assessing sustainability in industrial sectors including minerals and metals. LCA has proven to be a valuable tool for evaluating the potential environmental impacts of products and materials. The abiotic resource deletion within LCA is a complex and contentious issue, which remains unresolved to date. However, the vast endowment of minerals may not be exhausted soon, but extraction and production are becoming more challenging. From the early 1970s, following a range of high profile cases of poor reporting of mineral resources in the Australian mining industry (e.g. the Poseidon nickel affair, or Nabarlek uranium reserves bungle), the industry developed a systematic code to estimate mineral reserves and resources. Declining ore grades are indicative of a shift from 'easier and cheaper' to more 'complex and expensive' processing – in social and environmental terms as well as economic.

Introduction

LCA is a major sustainability assessment tool for industrial sectors, including minerals and metals. Although application of LCA to the minerals sector is relatively new, it has gained prominence in the recent past. In the past decade and a half, the use of LCA in the minerals sector has advanced knowledge through the development of scientifically valid life cycle inventory databases and models (e.g. EcoInvent, NERL, IVAM, EPS, Eco-Indicator 99, etc.). Yet, the current LCA models are grappling with some scientific anomalies in its application to the minerals sector. One such important issue is the quantification of abiotic resource depletion in LCA.

In the context of LCA abiotic resources are defined as "raw materials or means for production or consumption activities". Depletion of abiotic resources implies that the resources are consumed through intended or unintended physical disintegration or dissipation. Depletion leads to the reduced availability of the corresponding type of resource to future generations. There are numerous methodologies proposed for the impact assessment of resource use and they were categorised into four main approaches. Two out of four methodologies focus on current consumption, while other two types focus on future consequences.

The main objective of this article is to argue why mineral resources depletion is an issue that needs to be addressed in the LCIA stage in more detail and in what factors should be taken into consideration in underpinning the depletion related impact categories within LCA.

The Current Mineral Resource Reporting Systems – Unification is the Need!

Currently, there are a number of reporting systems used worldwide – leading to an inconstant approach in reporting the mineral resources or ore reserves. For example, the major mineral resources classification systems practiced worldwide are the USGS, the JORC Code, the NI 43-101 and the SAMREC. The JORC code was named after its committee, the Joint Ore Reserves

Committee Code – or 'JORC' Code, with its first edition released in 1974, and many updates and revision have been issued since. There are also equivalent codes in other major mining countries, such as USGS (USA), National Instrument 43-101 (Canada), SAMREC (South Africa) and so on. The USGS 'reserve' figures loosely correspond to what is defined to as 'measured, indicated & inferred resources' under the JORC code and/or NI 43-101 standard, and that the USGS's 'reserve base' figure includes speculative estimates of undiscovered resources that may or may not be economic.

The finite nature of individual mineral deposits and difficulties in finding more deposits with available technologies has led to many forecasts of resource depletion. The important reason behind the concerns over scarcity could be because of misleading interpretation of the data on the 'reserves' of various mineral resources due to variety of different reporting systems. This could be due to surplus of minerals available for mining and use and thereby no attention is being paid in exploring for new resources. Within the mining industry it is widely recognized that there exists little economic incentive to identify reserves beyond 20-30 years of consumption, given the costs of such efforts and the time value of money.

A consistent abiotic resource depletion framework: the need of the hour

Mining is a site specific activity and therefore has to take place wherever minerals exist, and is a land intensive sector. Land use by the mining industry, though temporary in nature, can lead to substantial local impacts, particularly on biodiversity and soil quality crucial to ecosystem sustainability. Coincidentally, most of the land where mining takes place is also an important habitats for highly diverse flora and fauna. Any mining and/or exploration activities could cause considerable, and at time irreparable, damage to the local land and biodiversity of the region, significantly affecting local natural resources. In addition, in such remote environments it is common for communities to engage in subsistence agricultural practices dependent on local natural resources. In these circumstances, the human (social and economic) dimensions of biodiversity are of critical importance.

Where minerals from underdeveloped countries are exploited by multi-national companies, the benefit as a result of mining, arguably, would not go to the underdeveloped nation. Further, in situations where companies only export ore concentrates, this limits the economic value added created domestically. Needed supplies and equipment are imported, skilled workers come from abroad, and few unskilled workers are necessary. Where these conditions hold, mining contributes little in the way of economic spillovers, and the benefits for the host country are limited to the taxes and royalties it collects.

When considering abiotic resources and their depletion concerns, it is critical to examine trends over time, as well as aspects such as ore grade and impurities. On the overall, the key trends affecting the mining industries are: i) declining ore grades; ii) increasing impurities; and iii) increasing mine waste (tailings and waste rock). Additional pressure on productivity are also expected to come from increasing costs and/or reduced availability of water and energy, as well as the phasing in of a cost for greenhouse gas emissions. Energy and water costs are increasing at the same time as energy use in total is growing. Furthermore, additional social and financial pressure is likely to arise from environmental damage associated with maintaining existing levels of production and attempts to significantly increase production.

Summary: Need a Holistic Methodology

This article briefly summarised the key issues and critical aspects in the methodology of current abiotic resource depletion framework. While the ore production rates forecasts worldwide are strongly pointing towards increasing trend, there are still large amounts of minerals still potentially available to be mined in in the world. However, the key trends affecting the mining industries are: i) declining ore grades; ii) increasing impurities; and iii) increasing mine waste (tailings and waste rock). So, any framework proposed should be holistic and must address the concerns of depletion from the perspective of environmental and socio-economic points of view.

10. INDICATORS OF RESOURCE DEPLETION: VIEWS OF THE MINING INDUSTRIES

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Abstract

Euromines members have articulated their "Views on Indicators of Resource Efficiency". Resource efficiency should yield optimum solutions to the trade-offs that exist between different environmental objectives and the environmental, social and economic imperatives of sustainable development. The European extractive industries fully support the premise that life cycle management approaches are required to describe and monitor resource efficiency. However, some serious methodological issues remain to be resolved before the proposed indicators can be used to reliably measure the environmental impacts of resource use. Notably, reserves are an economic indicator – not an environmental one. Run-of-mine ore-grades are not indicative of the state or condition of the natural resource. As cut-off grades decrease, the volume of mineral reserves increases. An improved uniform model should be developed that adequately reflects the full range of resource depletion potentials, so that efforts are not diverted away from more acute pressures on the environment. An improved uniform model should be developed that adequately reflects the full range of resource depletion potentials, so that efforts are not diverted away from more acute pressures on the environment.

Discussion

If applied incorrectly, "resource depletion", "material footprint" and "material consumption" concepts divert attention away from the environmental impacts of dispersive use and release by over-estimating the environmental impact of resource extraction (e.g., mining of phosphate rock). Recent EU research has revealed that current assessments of "Abiotic Resource Depletion" vary by several orders of magnitude and that there is no consensus amongst LCA practitioners on the issue of concern. In practice, some LCAs have prioritised "conservation" of abundant mineral resources over more pressing environmental concerns. Insufficiently informed interpretation of these studies (e.g., by a member of the public confronted with an aggregated indicator), is likely to lead to counter-productive diversion of effort.

As several geologists and resource economists have shown, "depletion" of mineral resources is not likely enough to be systematically included as an impact category in LCIA. "Scarcity" of these raw-materials is an economic issue arising from a lack of efficient forward-looking use of capital and not indicative of any environmental impact.

The current societal concern is partly fuelled by high prices due to the very recent emergence of the Brazilian, Russian, Indian and Chinese economies. However, prior to that, commodity prices were in continual long-term decline. Price peaks from the 20th Century corresponded to wars and revolutions – not from depletion of the natural resources. Otherwise, many commentators point to declining ore-grades as evidence of an environmental issue that should be of societal concern. However, the ore-grades referred to in those studies are invariably "run-of-mine" ore-grades, i.e. the grade of the ore that is sent by the mine for further processing. Run-of-mine ore-grades are not indicative of the state or condition of the natural resource. Run-of-mine ore-grades are indicative of the performance of the mineral supply industry. They have declined over time due to a complex set of influencing factors including the inherent competitive advantage of large established mines and - most especially - technological advances that have enabled the profitable

extraction of metals from lower-grade ores despite long-term price erosion. The volume of a mineral reserve increases as the cut-off grade of extraction technologies decreases, so as technology enables profitable processing of lower-grade ores, the volume of the available mineral reserves increases. Production of many metals, e.g., copper, has increased dramatically over the same period that run-of-mine ore-grades have declined. Still, the net result of resource extraction and resource discovery over a given period of time is almost always an *increase* in available natural resource. Meanwhile, the range of copper content in discovered porphyry copper deposits, for example, has remained remarkably similar since 1845, with no discernible decrease or increase over the last 150 years.

Those concerned about depletion of abiotic resources have claimed that Domestic Material Consumption increases inexorably with Gross Domestic Product, the resources are non-renewable, and therefore such economic growth is unsustainable. Such assertions have contrasted strongly with data typically presented by geologists and minerals economists. New studies present an opportunity to analyse these differences and attempt resolution. A recent report by the Sustainable Europe Research Institute (SERI) analyses the Resource Productivity trends of all countries worldwide between 1980 and 2008. It confirms that each economy takes a slightly different path according to its industrial base, inherent strengths and weaknesses and historical context and that, as a whole, the world has been progressively de-coupling from resource consumption for at least the last 40 years.

Rather than being truly depleted, the majority of mineral resources are used to continuously serve valuable purposes in the built environment. The Resource Depletion impact category should therefore only be included in LCIAs of products that are consumed (typically those derived from biotic resources such as fish, crops, some forest products, livestock, foodstuffs, oil, gas, peat and coal) for which there may be imminent risk of environmental impacts if stocks cannot be regenerated. It is suggested to continue to improve resource depletion indicators and methods to make them fit for purpose; apply them only where sustainable yield is threatened; or at least capture the full range of depletion potentials (from extremely low to high enough for concern); and transparently report which datasets are used for which materials.

11. DEFINING CRITICAL RAW MATERIALS IN THE EU: INFORMATION GAPS AND AVAILABLE SOLUTIONS

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Abstract

In order to secure the access to raw materials EU launched in 2008 the Raw Materials Initiative. The identification of critical raw materials for the EU economy has been performed with the scope of monitoring materials with insecure supply and prioritizing policy actions.

Three components are taken into account in the assessment: economic importance, supply risk and environmental country risk. This summary briefly describes the adopted methodology and the outlook of EU policy on raw materials.

Introduction

Modern societies rely to a large extent on a secure supply of raw materials, which constitute the material basis of our economy. The availability and the undistorted access to these resources are of utmost importance for the competitiveness of EU economy, which is highly dependent on import of strategically important raw materials, e.g. high-tech metals, used, for instance, in low carbon energy technologies.

In recent years raw materials global markets have been experiencing high price volatility and an overall increasing trend; the demand of materials has increased worldwide and some producing countries have applied protectionist measures and export restrictions.

The policy response of the European Union to these challenges lies in the Raw Materials Initiative (EC - European Commission 2008a), that have been launched in 2008 and reinforced in 2011.

Three main pillars are integrated in this initiative that covers the non-agricultural and non-energy raw materials:

- Ensure level playing field in access to resource in third countries
- Foster sustainable supply from European sources
- Boost resource efficiency and recycling

One priority action of the Initiative was to identify a list of critical raw materials at EU level. The methodology used to obtain the list is illustrated in the next section, then the outcomes of the study are described. Conclusions outline the future targets of the EU policy on raw materials.

Criticality assessment

The concept of criticality in a relative one – materials considered critical are those that have relatively higher supply risk and higher economic importance than others. The critical raw materials list serves as a reference for prioritizing policy actions.

The report by an ad-hoc working group on critical raw materials, a sub-group of the Commission Expert Group "Raw Materials Supply Group" adopted a "pragmatic approach" to the identification of materials which could be subjected to supply restriction in the next future (EC - European Commission 2010). The study considered a time horizon of ten years.

The criticality concept applied in this study does not consider the geological scarcity of resources, since this is not considered a risk in the given time horizon.

Three components are taken into account in the assessment:

- **Economic importance**, based on use of each material per a defined mega-sector weighted by the value added of the sector that uses this materials as production input
- **Supply risk**, which encompassed four sub-components:
    - *level of concentration of worldwide production* of raw materials, using the Herfindahl-Hirschman Index (HHI) which accounts for market competitiveness;
    - *political and economic stability of the producing countries*, using the World Bank indicator Worldwide Governance Indicator which consider four aspects of governance: voice and accountability, political stability and absence of violence/terrorism, government effectiveness, regulatory quality, rule of law, control of corruption;
    - *potential of substitution of the raw materials*, based on a substitutability index estimated through experts' opinion and aggregating the substitutability for the different uses;
    - *recycling rate*, considering the shares of EU consumption of raw materials addressed through secondary materials;

The aggregation of the four elements listed above has been performed using the formula:

$$SR_i = \sigma(1 - \rho_i)\, HHI_{WGI}$$

Where:

$$SR = supply\, risk$$

$$\sigma = substitutability = \sum_s A_{is}\, \sigma_{is}$$

$$A = share\, of\, a\, raw\, material\, consumption\ \ in\, a\, given\, end\, use\, sector$$

$$i = raw\, material$$

$$s = end\, use\, sector$$

$$\rho = recycling\, rate = ratio\, of\, recycling\, from\, old\, scrap\, to\, EU\, consumption$$

$$HHI = \ Herfindahl - Hirschman\, Index$$

$$WGI = Worldwide\, Governance\, Index$$

- **Environmental country risk**, which refers to the risk that producing countries could implement environmental protection measures, thus constraining the raw materials' supply. It is measured with the Environmental Performance Indexes (EPI) of the producing country, weighted for the production figures.

Outcomes

The resulting list of critical raw materials is derived considering the materials with a relatively high supply risk and economic importance, setting thresholds for the two dimensions and selecting the group having relatively higher scores for both the dimensions (fig.1). The inclusion of environmental country risk data did not change the list, which includes:

- Antimony
- Beryllium
- Cobalt
- Fluorspar
- Gallium
- Germanium
- Graphite
- Indium
- Magnesium
- Niobium
- PGMs (Platinum Group Metals: platinum, palladium, iridium, rhodium, ruthenium and osmium)
- Rare earths (yttrium, scandium, lanthanum, cerium, praseodymium, neodymium, promethium, samarium, europium, gadolinium, terbium, dysprosium, holmium, erbium, thulium, ytterbium and lutetium)
- Tantalum
- Tungsten

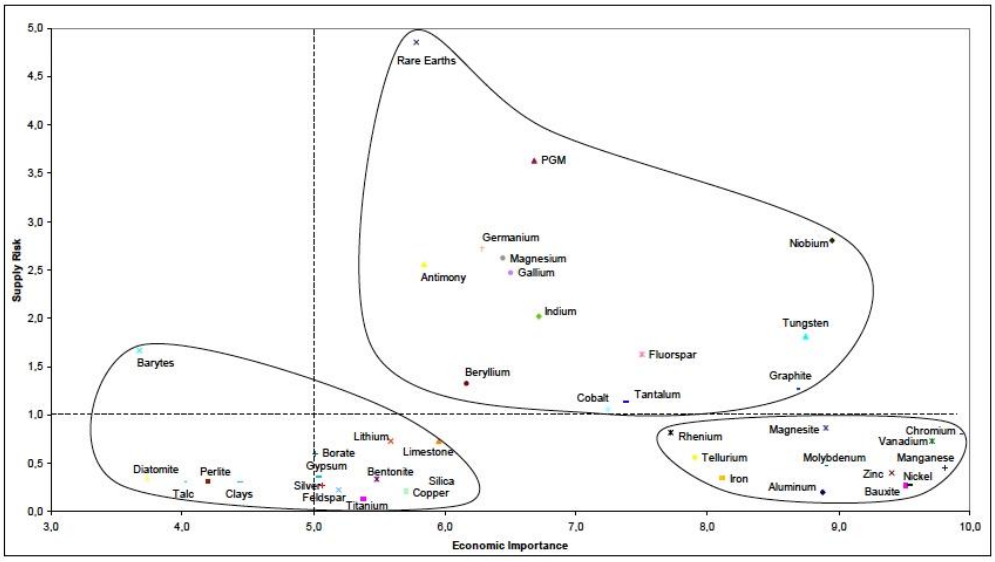

Figure 11.1 Outcome of the EU criticality assessment

Conclusions and 2020 targets

The assessment of critical raw materials used indicators based on annual data, thus it delivers a snapshot of the current state, highlighting materials facing relatively higher risk of supply disruption and on which policy actions should focus on. The assessment will be instead repeated at least every three years, in order to re-assess the priorities.

In order to tackle the challenges of raw materials and promote resource security, EU has also launched the European Innovation Partnership on Raw Materials (EC - European Commission 2012).

They have as main objectives to reduce import dependency, provide alternatives in supply, push Europe to the forefront in raw materials sectors and mitigate negative environmental impacts. The European Commission has also set concrete targets to be achieved by 2020 which include up to 10 innovative pilot actions for exploration, extraction and processing, collection and recycling; substitutes for at least three key applications of critical and scarce raw materials; enhanced efficiency in material use and in prevention, re-use and recycling of valuable raw materials from waste streams (with a specific focus on materials having a potentially negative impact on the environment); a dynamic modelling system linking trends in supply and demand with economically exploitable reserves and a full lifecycle analysis.

12. CRITICALITY SCREENING FOR RAW MATERIALS IN ENERGY TECHNOLOGIES

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Abstract

In recent years there has been a worrying rapid growth in demand for raw materials, which has led to much concern worldwide. The EU is tackling this problem through the Raw Materials Initiative and the European Innovation Partnership on Raw Materials. In support of these policy initiatives, the JRC/IET conducted in 2011 a study to assess whether there could be any potential bottlenecks to the large-scale deployment of low-carbon energy technologies due to the shortage of certain materials, namely metals. The study focused especially on the demand of metals from the six low-carbon energy technologies of SET-Plan, i.e. nuclear, solar, wind, bioenergy, carbon capture and storage (CCS) and the electricity grid. A criticality screening was performed using market and geopolitical factors, which showed that five metals were of a high risk, namely: indium, tellurium, gallium, neodymium and dysprosium. A follow-up study has been recently performed looking at other low-carbon technologies that are competing for the same metals. This second study has shown that, under similar criticality criteria, the six rare earth elements: dysprosium, europium, terbium, yttrium, neodymium and praseodymium, and the two elements gallium and tellurium, are of a high risk.

Introduction

There has been a rapid growth in demand in recent years for raw materials, including minerals and metals for which the supply of some into the market has been constrained by the policies of major producers. This has led to much concern worldwide, especially in the EU, where many industries have come to rely on materials that have an associated supply risk. The EU is tackling this problem through its Raw Materials Initiative (EC - European Commission 2008a) and the European Innovation Partnership on Raw Materials (EC - European Commission 2012). In support of these policy initiatives, the JRC/IET conducted in 2011 a study to assess whether there could be any potential bottlenecks to the large-scale deployment of low-carbon energy technologies in the EU due to the shortage of certain metals (Moss et al. 2011; Moss et al. 2013). The study focused especially on the demand of metals from the six low-carbon energy technologies of SET-Plan, i.e. nuclear, solar, wind, bioenergy, carbon capture and storage (CCS) and the electricity grid.

The metal requirements in each of the technologies was estimated based on the most optimistic deployment-scenarios for 2020 and 2030, thereby creating a first screening to filter out those metals where no shortage threat is likely in the foreseeable future. The analysis then scrutinised the demand with respect to market and geopolitical factors, such as rapid future global demand growth and the concentration of supply and political risks associated with key suppliers. Furthermore, the analysis took into account that some technologies, depending on the technology scenario chosen, may have different sub-technology mixes. For example, the capacity of solar PV technology will comprise crystalline silicon and different thin-film technologies, where the future dominance of one (sub-) technology over another may lead to even higher demand figures for some metals. The study found that five metals were of a high risk, namely: indium, tellurium, gallium, neodymium and dysprosium.

As a follow up and to supplement the first study, a second study has recently been completed that aimed to identify those metals which could be a potential supply-chain bottleneck to other low-carbon energy technologies, as well as other selected critical technologies for the European economy. The second study considered technologies such as fuel cells, electricity storage, electric vehicles, lighting, technologies that improve energy efficiency in industry and buildings and any other technology that may be competing for the same resources. Where possible, this second study models the implications for materials demand as a result of the scenarios described in the EU Energy Roadmap 2050 (EC - European Commission 2011e; Johnson Matthey 2012).

The combined results from both studies are presented here.

Each study also addressed possible mitigation strategies, such as improving domestic mining, materials reprocessing (reuse), recycling and R&D with respect to substitution and more efficient use of critical materials. However, these will not be discussed in this workshop.

Methodology

The methodology is based on a bottom-up approach, i.e. first compiling an inventory of all metals used in each technology, followed by an analysis to identify which metals appear significant (e.g. using criteria based on supply and demand, thereby eliminating 'safe' materials from the analysis). For each technology an appropriate functional unit (e.g. kg/MW) was used to quantify the requirements alongside projections of technology uptake. The widest selection of metals was included, encompassing metallic elements, metallic minerals and metalloids. In total the usage of sixty different elements was considered, with iron, aluminium and radioactive elements specifically excluded. The usage of graphite was also considered, given its identification as a critical raw material.

The latest available data for metals supply estimates is for 2011. Materials demand estimates are also compared against long term supply projections for 2020 and 2030, thus providing a more dynamic measure of materials availability. The main source of data used for the long term supply projections is historical supply data collated by the United States Geological Survey (USGS) Mineral Commodity Specialists for around 90 mineral commodities (US Geological Survey 2011). Long term supply trends were linearly extrapolated to form the supply projections to 2030. Supplementary data for some metals where additional data was felt to be useful, has also been collected. For example, for the platinum group metals and rare earth elements, additional data (Johnson Matthey 2012) has been used to identify the composition of supply of the individual metals.

As in the first study, a criticality analysis was performed based on both market and geopolitical factors. Based on the ranking and combination of risks, a reduced list of metals is derived. These metals are regarded as 'critical'. A number of the metals identified in the first JRC study were re-assessed for their criticality. The analyses from both studies were brought together to form one overall criticality ranking for the EU path to the decarbonisation of the energy sector.

Results

A total of 60 materials of relevance were found, hence it is not practical to produce a detailed forecast for each of them. Also due to volatility that is inherent in many commodity markets - particularly those for many minor metals - a long-term forecast cannot be considered reliable. Indeed, even for the base metals (i.e. copper, lead, nickel, steel, tin and zinc) for which the markets are much more transparent and less volatile than the minor metals, most forecasts are only for a period of around 2-5 years. It is therefore clear that the projections here should not be regarded a forecasts.

The approach taken in the first JRC study to screen the list of metals was to impose a cut-off at 1% demand within the technologies as a percentage of current (2010) world supply estimates. However, in the second study, projected supply has been used, thus making sense to apply a lower cut-off value. To ensure consistency with the first study this was set at around 0.3% of projected

supply, with the effect of including the 14 elements previously identified as significant retained in this analysis.

On the basis of projected supply, 32 materials were identified as being significant. The metals are shown in Figure 12.1 in order of highest demand to supply, and further in the list below, indicating also the key associated decarbonisation technology. It is apparent that the greatest magnitude and number of materials is associated with vehicles. Solar, wind, fuel cells and lighting are each associated with at least one of the materials with a requirement above 5% of world supply. Several of the metals identified (Table 12.1) within the sector study (e.g. indium, lead, tantalum, gallium, copper, tin and rare earth elements) are included on the reduced list.

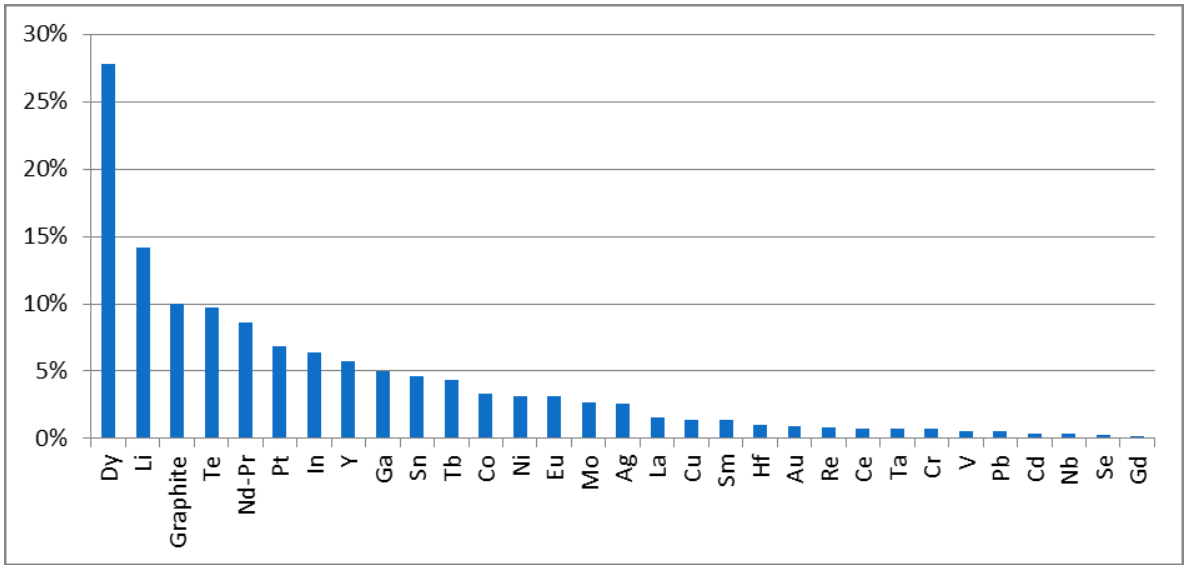

Figure 12.1 EU metals demand for decarbonisation technologies, as % an average supply 2020-2030

The 32 metals and their principal applications are as follows:

Table 12.1 List of metals identified as critical within the sector study

1. Dysprosium (vehicles, wind)
2. Lithium (vehicles)
3. Graphite (vehicles)
4. Tellurium (solar)
5. Neodymium (vehicles, wind)
6. Praseodymium (vehicles, wind)
7. Platinum (fuel cells)
8. Indium (solar, lighting, nuclear)
9. Yttrium (lighting)
10. Gallium (lighting, solar)
11. Tin (solar)
12. Terbium (lighting)
13. Cobalt (vehicles, fossil fuels)
14. Nickel (desalination, vehicles, geothermal)
15. Europium (lighting)
16. Molybdenum (desalination, wind)
17. Silver (solar, lighting)
18. Lanthanum (vehicles)
19. Copper (CHP, solar, vehicles, grids)
20. Samarium (vehicles)
21. Hafnium (nuclear)
22. Gold (lighting)
23. Rhenium (fossil fuels)
24. Cerium (vehicles)
25. Tantalum (geothermal, fossil fuels)
26. Chromium (desalination)
27. Vanadium (CCS)
28. Lead (grids, storage)
29. Cadmium (solar)
30. Niobium (CCS)
31. Selenium (solar)
32. Gadolinium (lighting)

Criticality screening

The risk of the availability that a metal may have, is not a quantitative factor, such as in the previous section where demand is compared to supply, but a qualitative factor, e.g. the source of

the metal and its degree of difficulty in extraction are just two of a number of factors that must be taken into account when looking at availability. Due to the forward-looking nature of this study, it is crucial to consider supply and demand forecasts for each metal. Consequently, each metal was examined regarding reserve data, production, key applications, processing routes, dominant supplying countries and political risks, price developments and supply and demand forecasts. The factors can be reduced essentially to four evaluators: two on market factors and two on geopolitical factors. The four evaluators are:

- *the likelihood of rapid global demand growth*, which refers to risks persisting if demand from significant applications other than low-carbon energy technologies is expected to grow rapidly over the coming years;
- *limitations to expanding global production capacity in the short-to-medium term*, which refers to risks if suppliers are unable to expand output relatively easily in the short-to-medium term in response to demand and price increases, e.g. due to a lack of known reserves, a lack of idle production capacity or because the metal is a by-product of other mining activities;
- *the cross-country concentration of sup*ply, which refers to risks emanating from the structure of supply (monopolistic or dominated by only a few players), since individual large supplier countries have sufficient market power to affect global price levels and aggregate supply through policy decisions;
- *the political risk related to major supplying countries*, which refers to risks caused by a broader political instability or internal conflicts in a major supplying country, which may reduce or delay investments or disrupt production and can have significant impact on global production capacity, including the likelihood that individual suppliers will seek to restrict access.

This criticality screening resulted in the ranking Table given below. Eight elements are given a high criticality rating and are therefore classified as 'critical'. These include six rare earth elements (dysprosium, europium, terbium, yttrium, praseodymium and neodymium), as well as gallium and tellurium. The other elements are given lower criticality levels, but the elements graphite, rhenium, indium and platinum are categorized as near-critical.

Figure 12.2 Criticality assessment for EU path to the decarbonisation of the energy sector

Element	Rating
Rare Earths: Dy, Eu, Tb, Y	High
Rare Earths: Pr, Nd	High
Gallium	High
Tellurium	High
Graphite	High-Medium
Rhenium	High-Medium
Indium	High-Medium
Platinum	High-Medium
Rare Earths: La, Ce, Sm, Gd	Medium
Cobalt	Medium
Tantalum	Medium
Niobium	Medium
Vanadium	Medium
Tin	Medium
Chromium	Medium
Selenium	Medium-Low
Lithium	Medium-Low
Hafnium	Medium-Low
Molybdenum	Medium-Low
Silver	Medium-Low
Nickel	Low
Gold	Low
Copper	Low
Cadmium	Low

Conclusions

The implications of the demand for the 32 most significant materials were shown in the previous section. Dysprosium was identified as being the most 'at risk', with the EU requiring nearly 30% of expected world supply to meet EU demand for hybrid and electric vehicles and wind turbines. Based on the combination of supply-chain risks, the most critical categories were:

- Eight metals were given a high criticality rating and are therefore classified as 'critical'. These include six rare earth elements (dysprosium, europium, terbium, yttrium, praseodymium and neodymium), as well as gallium and tellurium.
- Four materials were given a high-medium rating and are classified as 'near critical'. It is suggested that the market conditions for graphite, rhenium, indium and platinum are monitored in case the markets for these metals deteriorates thereby increasing the risk of supply chain bottlenecks.

Unlike most criticality studies where the economic relevance of a raw material is derived from its overall importance for the target national economies, the analysis presented here and in similar studies (US Department of Energy 2010; Moss et al. 2011) is driven by interest in particular energy technologies.

13. CRITICAL MATERIALS ASSESSMENT AND EARLY WARNING

Paul Telleen

U.S. Department of Energy

Abstract

This presentation summarizes the U. S. Department of Energy's (DOE) Critical Materials Strategy and discusses the methodology it used to determine criticality among a range of materials important to clean energy. The Critical Materials Strategy, which aims to help inform policymakers and the public, focuses on several energy technologies expected to experience high growth in coming years and includes criticality assessments, market analyses and technology analyses to address critical material challenges. The presentation also discusses methodological approaches to identifying critical minerals more dynamically as part of an "early warning system" to track changes in criticality over time.

U.S. Department of Energy's *Critical Materials Strategy*

In 2010 and 2011 DOE produced reports on critical materials in the energy sector. The reports highlight the importance of certain materials to wind turbines, electric vehicles (EV), photovoltaic (PV) thin films, and energy-efficient lighting, as well as catalysts used in oil refining (US Department of Energy 2010; US Department of Energy 2011). The scope was limited to certain energy technologies, and did not assess criticality across the entire U.S. economy. The principal focus was on four of the fastest growing clean energy technologies – vehicles, wind, solar power and energy-efficient lighting. The reports identified important materials used in these technologies, which come from a wide cross-section of the periodic table, including rare earth elements.

The methodology for assessing energy critical materials began with building demand projections across the four clean energy technologies. Estimates of future demand for key materials in clean energy applications were calculated as the product of three factors: 1) deployment: total units of the clean energy technology in a given year; 2) market share: the percentage of installations captured by a specific clean energy application; and 3) material intensity: demand for the material in each unit of the clean energy application. These factors are all interconnected and depend on a variety of technological, regulatory, and market variables. A "high market penetration" variable and a "low market penetration" variable were developed using deployment scenarios developed by the International Energy Agency and market share estimates from industry experts. Next, low and high materials intensity cases were included based on anticapted R&D advances and current technology, respectively. The result was four demand trajectories ranging from high market penetration and high material intensity to low penetration and low intensity for each material.

Combining demand trajectories with current and estimated future supply yielded supply and demand projections. These projections, along with other supply and demand factors, were used to build a criticality matrix for the short and medium-term time frames. The two axes of the matrix were 1) importance to clean energy technologies and 2) risk of supply disruption. These dimensions were in turn based on weighted variables such as basic availability of a material; political and social factors; co-dependence on other markets; and substitutability limitations, among others.

Between the short term and the medium term, the importance to clean energy and supply risk shift for some materials. For example, in the 2011 assessment neodymium's importance to clean energy increases while the importance to clean energy decreases for europium, terbium and yttrium (and the supply risk for europium also decreases). See Figures 13.1 and 13.2. Despite these changes, neodymium, europium, terbium and yttrium all remain critical in the medium term. These materials are used either in magnets for wind turbines and EVs or in lighting phosphors. The supply

risk for indium also decreases, making indium not critical in the medium term. On the other hand, both the importance to clean energy and the supply risk for lithium increase, making lithium near-critical in the medium term.

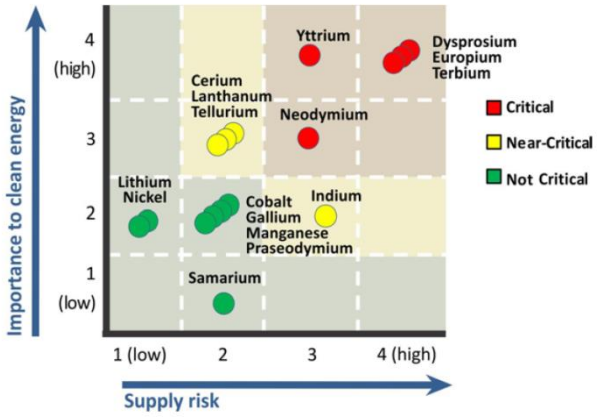

Figure 13.1: Short-Term (present-2015)

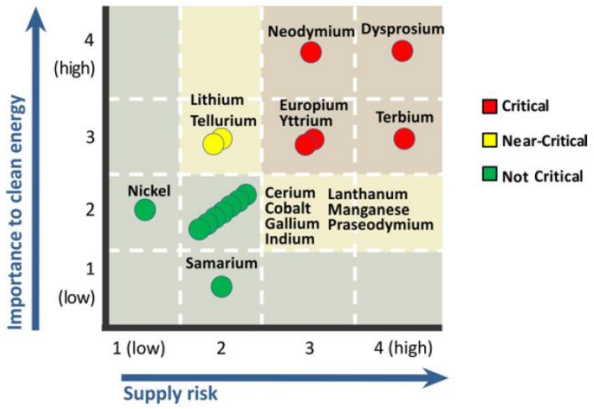

Figure 13.2: Medium-Term (2015-2025)

Comparing the short term criticality assessments from the 2011 *Critical Materials Strategy* to the 2010 report, a number of changes are evident. For instance, the importance to clean energy has increased for some rare earth elements in lighting phosphors (yttrium, europium, terbium); the supply risk for neodymium has decreased due to higher levels of anticipated production and reduced demand; and the importance to clean energy has decreased for indium and gallium due to a more pessimistic outlook for CIGS thin-film PV cells. These shifts in criticality demonstrate how conditions can quickly change and thus require an increased awareness of variations in future criticality assessments.

An Approach to Early Warning Assessment

Building on DOE's *Critical Materials Strategy* and similar work by other agencies, a process is underway to develop a whole-of-economy approach to critical materials. According to the U.S. National Science and Technology Council, "a material or mineral is critical if it serves an essential function in the manufacture of a product –the absence of which would cause economic or social consequences – and if its supply is vulnerable to disruption."

U.S. government coordination on critical materials is being led by the White House Office of Science & Technology Policy and includes the Departments of Energy, Defence, Commerce, Interior and

State, as well as the Environmental Protection Agency. It convenes working groups on topics related to criticality assessment and early warning, long term R&D options, and information transparency.

Early warning is particularly useful because it can provide for timely policy decisions and research investments related to critical materials. It also identifies issues early to ensure optimal solutions and help prevent future problems. Certain data and analytical characteristics will help ensure an effective early warning process. These include timely data, a quick and repeatable preliminary analysis, and a more detailed analysis to understand systems effects.

One potential approach to early warning is based on three stages of analysis. The first is a preliminary screening of materials or "triage" based on certain indicators that focus on change. This helps to reduce the number of minerals to be examined. The next stage is a more in-depth analysis that begins with an assessment of national importance, both in economic terms and importance to national policy (such as clean energy goals, national defence or health care, etc.). Those materials considered nationally important are then given a thorough supply chain analysis to fully understand specific risks at different stages of the supply chain. Finally, interpretation of the results can lead to recommendations for policy, R&D investments, or further methodological refinement.

Some possible preliminary screening indicators include the concentration of material supply and/or production in a few countries, restrictive trade policies in producer countries that distort the market, and co-production and by-production of certain minerals, which represent other sources of demand that are difficult to control and may constrain markets further. Also, increased demand pressure can signal emerging uses of particular technologies that will strain supply and create tight markets in the near future. Market volatility, such as that reflected in price movements, is another key indicator that can signal underlying changes in materials markets that require further exploration.

The next stage of analysis would be a more in-depth look at the materials from the preliminary screening. Most importantly, an assessment of the importance of a given material is required to identify those that matter most to the nation. Two variables, economic importance and importance to national policy, can be thought of as indicators of materials that are of "national importance" or the national interest. Some possible indicators of national importance include the value of domestic consumption of a material's primary end-use, which speaks to the level of dependence the economy has on the particular end-use, or the value of domestic production of a material's primary end-use, which speaks to how important a particular end-use is to domestic firms that produce it. Again, a particularly useful indicator is the growth rate of the consumption and production value, since such measures would indicate whether a particular end-use is growing in importance or not, and thus yields a more dynamic and appropriate picture of importance. The pursuit and achievement of certain public policy goals can be just as important to the national interest. Policy importance indicators include statutory, regulatory and policy goals developed by government.

Conclusion

The DOE *Critical Materials Strategy*, like other similar analyses, offers a snapshot of material criticality in the clean energy economy. Such assessments can be built upon to develop an early warning methodology that captures changes in criticality over time. Both an initial rapid screening and an in-depth analysis can contribute to early warning. A more dynamic approach to criticality can help policymakers be more proactive, instead of reactive, in the face of a rapidly changing global market for minerals.

14. CRITICALITY OF MINERAL RAW MATERIALS AND SUSTAINABILITY ASSESSMENT

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What are critical raw materials?

The concept of criticality of mineral raw materials, though in itself simple enough, suffers from considerable misinterpretation due to its suggestive name. Therefore, one of the key goals of this presentation was to introduce the concept of criticality of mineral raw materials as currently applied by practitioners.

The first aspect of criticality is that it is a relative, not an absolute concept. It is therefore not possible to do a criticality analysis for a single or even a very small number of raw materials without having a frame of reference, a set of threshold values for the relevant indicators that allow for a raw material to be classified as critical or not. In turn, these threshold values are the product of a political or business (see below) decision rather than the product of rigorous derivation.

Second: a criticality analysis has at least two dimensions connected by a logical "AND". The dimensions, illustrated in Figure 14.1 are borrowed from traditional risk analysis: how likely is an event to occur (risk) and how large would the impact of such an occurrence be (impact)? The relevant risk dimension in this case is the risk of a supply shortage (with ensuing price spikes), while the impact dimension has been interpreted as either the negative economic impact of a shortage (but there is currently no satisfactory way of estimating this) or the economic importance of a raw material to an economy (e.g. the EU27) hinting at but not actually attempting to quantify possible negative impacts. Note that there need not only be one risk dimension: the EU assessment for critical raw materials had two risk dimensions—one arising from political reasons and one from environmental reasons; a similar approach was proposed by (Graedel et al. 2012) using a 3D graphical presentation.

Third, because criticality is a relative concept and the relevant dimensions can (and should) be defined by the user according to his/her particular needs, it is only logical that the indicators deemed relevant and the specifics of the methodology applied will lead to different results for countries or group of countries (e.g. US, KR, DE, EU27), for parts of countries (e.g. the Bavarian assessment), for sectors (e.g. the reports focusing on green energy by the US DoE and the EU JRC) or individual companies. Furthermore, because the selected indicators have to be measured/estimated at some point in time, criticality analyses are generally a snapshot of the current/recent situation, and the assessment can change if large enough changes occur in the individual indicators. Thus, it is important to bear in mind that criticality assessments are meant to focus the attention of policy/decision makers on current/pressing issues and invite the reader to explore the underlying causes for the relative ranking. However, this important background information cannot be conveyed by a simple 2D graphic or list.

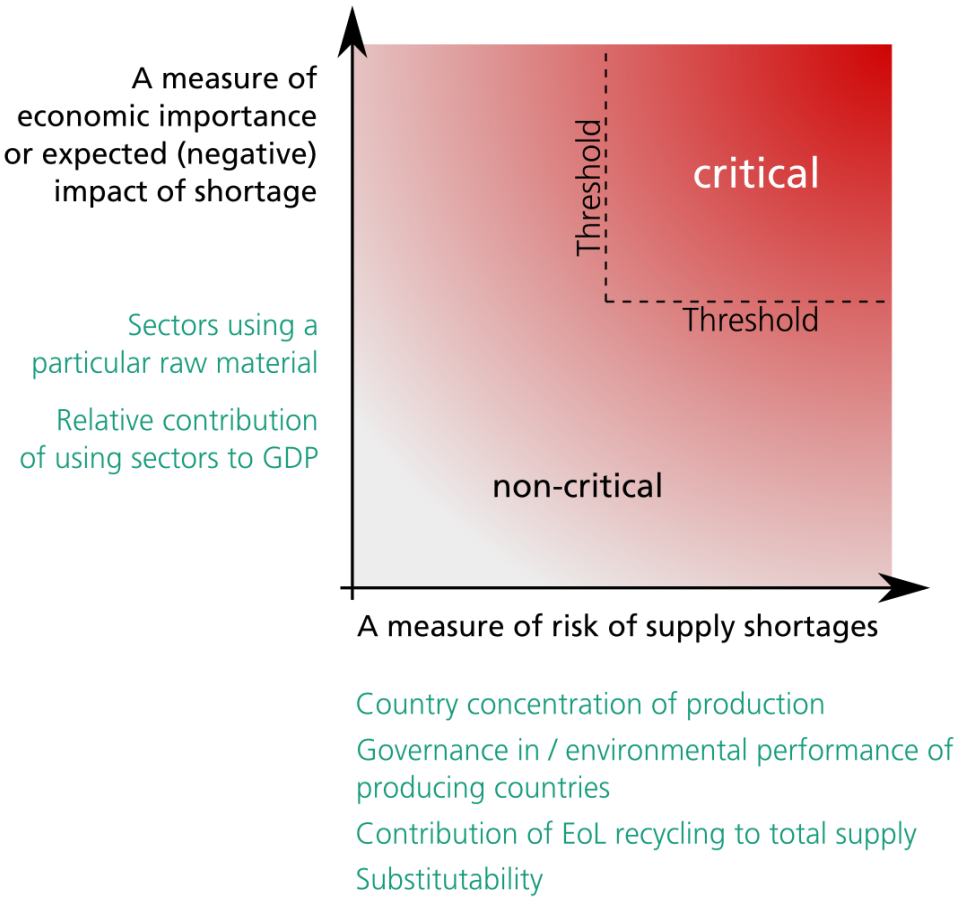

Figure 14.1 Graphical illustration of the concept of criticality of raw materials using a 2D matrix. The use of this type of graphic was introduced by (Committee on Critical Mineral Impacts on the U.S. Economy et al. 2008). The figure is based on (Buijs et al. 2012) and the indicators are those used in (Ad-hoc Working Group on defining critical raw materials 2010).

From the author's point of view, there are several links between criticality assessments and sustainability assessments as carried out by the industrial ecology community. However, the links seem to be logically one-sided: criticality assessments can draw from the data and experience from tools such as LCI/LCA and SFA/MFA (e.g. expected environmental impacts, recycling rates and potentials, etc.) but there is no obvious place for flow of information in the other direction.

15. HOW TO INCLUDE SECURITY OF RESOURCE SUPPLY IN SUPPLY CHAIN SUSTAINABILITY ASSESSMENT AND LCA?

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Abstract

Although supply risk of resources is an issue of concern of policy makers and industry, this is not explicitly included in the impact assessment methodologies currently used in LCA. This paper aims at discussing how supply risk and vulnerability to supply restrictions can be considered in the assessment of resource scarcity and socio-economic impacts related to raw materials within supply chain sustainability assessment and LCA. The components included in methodologies for criticality of raw materials are listed and compared with those currently in LCA methods to identify mismatches. The meaning of a 'resource security' indicator is discussed and recommendations for the scope of LCA related to this theme are made.

Introduction

In addition to the biophysical availability of abiotic resources, resource supply might be constrained for trade, for example by high concentration of a resource in a few producing countries and stressed when these countries face political instability. However, supply risk of resources is not explicitly included in the impact assessment methodologies in Life Cycle Assessment (LCA) as well as other aspects usually covered in Criticality approaches.

Criticality of raw materials is an established field for several decades but with an increasing interest lately, above all in the political agenda. Erdmann and Graedel (2011) made a review and analyses of current approaches for criticality assessments. The aspects mentioned in these methodologies tend to be the same but the way they are organized and grouped within the methodologies varies. In the figure below there is an illustration of the aspects covered by the methodology recently proposed by Graedel et al. (2012).

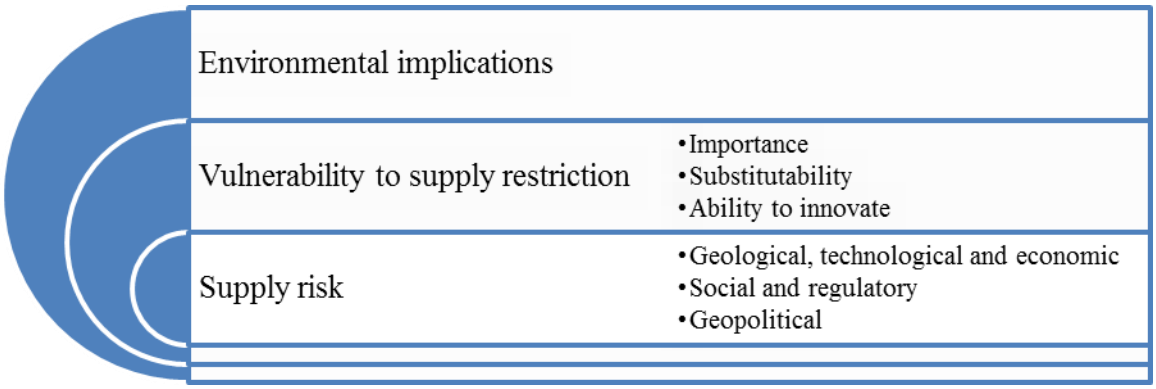

Figure 15.1 Components covered by criticality assessments (Graedel et al., 2012)

In this paper, the integration of security of resource supply in LCA methodologies is discussed by comparing these with criticality methodologies.

Discussion of integration of criticality aspects in LCA

Covered by traditional LCA

LCA is an instrument for identifying potential impacts of a product or service over its entire life cycle. LCA in its traditional form is of environmental nature, hence also named environmental LCA (E-LCA), and therefore it assesses the potential impacts of an interaction with nature resulting from anthropogenic activities along a life cycle. Primary extraction of fossil and mineral resources is such an activity and it causes decrease in the physical availability of a specific resource in the earth crust. For this reason, there is a consensus among practitioners that E-LCA should include the potential impacts of resource extraction on the future availability. However, most resources are very abundant when compared to their reserves, and for these resources, depletion will only occur far in the future.

Within the E-LCA context, there are some different views on what resource indicators should express. But the recent guidance on impact assessment methodologies from the JRC makes clear that only factors which directly are related with the geological availability of resources should be accounted for, which is the case for all life cycle impact assessment methods currently addressing abiotic resource use (EC - European Commission 2011a). Components such as recyclability, technological development, population and economic growth and substitution which greatly influence the future availability can also be considered in E-LCA. Moreover, these aspects were also identified as relevant for inclusion by various stakeholders during a stakeholder consultation hearing (Vieira et al. 2011; Vieira et al. 2012).

However, some of these aspects are difficult to estimate. Emerging technologies play a particularly important role for metals but how can these be estimated? Should substitution also be accounted in the future demand scenarios? Or is this assumed as a replacement only in case criticality is observed?

Not covered by traditional LCA

The importance of the resource to the entity being analysed, often a country, is a component often included in criticality metrics. This component aims at assessing how serious a specific resource is for the economy of the entity studied. This is not connected to the natural environment or to the physical availability of a resource but it is unquestionably a concern for companies, countries and other organizations. Similarly, supply risk resulting from social, regulatory and political factors is perceived as a risk for organizations but these are again not linked to physical availability but to socio-economic factors.

Cross-cutting issues

LCA is moving towards spatial differentiated impact assessment methods to address different cause-effect chains per location. However, because the resource market is global, spatial differentiation is not necessary in the E-LCA context if only the components mentioned in the previous section are included.

Conclusion

Security of resource supply is an issue of concern and companies and governments want to be able to identify where they may have a supply constraint in the near future. I would recommend excluding components as economic importance, social, regulatory and political components from the traditional E-LCA context. It is nevertheless also my believe that a separate discipline is needed to identify potential supply risk threats and/or the vulnerability to supply restrictions, defined as critical, in a product's life cycle.

16. UNITING MATERIALS SECURITY WITH LCA – A WIDER VIEW ON ADDING VALUE TO SUSTAINABILITY

Adrian Chapman

Oakdene Hollins, UK

This summary outlines a presentation given by the author at the workshop detailed above. As such it describes the opinions and proposals put forward by the author, and therefore should be considered as a discussion document.

Conceptually the alignment between materials security and LCA thinking in sustainability is clear. However, bringing these two areas together in practice to produce a useful and constructive result is more challenging. Care must be taken to avoid trying to "place a square peg in a round hole".

Much of the difficulty in combining LCAs with materials security work lies in the differences in their approach, scope and purpose. For example, the outputs of an LCA are typically used an indication of environmental impact. By comparison, materials security focusses on assessing the criticality of a material, by evaluating uncertainty or risk in a relative way to other materials. Therefore this is perhaps more closely linked to economic (or socio-economic) aspects of sustainability. Another contrast is linked to scope; materials criticality focusses on the mining and production of raw materials, whereas LCAs may take a whole lifetime view which is beyond just the production of materials. Despite these differences, there are various aspects of each with could be brought together to add value to sustainability.

Adding value to materials security with LCA

The methodologies used and outputs of materials criticality studies may provide some useful opportunities to apply LCA to aid with understanding the impact or mitigation. Criticality assessments used in material security work generally identify a set of materials which are considered "critical" within a specific context. For example, critical to the economy of a certain region, critical due to their use in a specific area of technology, or critical due to their importance to a company's supply chain. Further evaluation can then yield different mitigation strategies for these materials or uses. If applied correctly, LCA could be used as to enhance areas of materials security. Examples include:

As part of a criticality assessment, for example:

- Facilitate the prioritisation of critical materials in relation to each other,
- Identification of hotspots in production for consideration,
- Inclusion of an impact assessment of future events such as increased production, changing ore grades, altering by-products processing, and climate risks on supply.
- As a comparator between critical materials, for example;
- Evaluate trade-offs between environmental benefits of using different materials in an application,
- Comparison of lifecycle stages and uses for materials in applications.
- Evaluation mitigation strategies, for example;
- Impact of substitution of material, component or system,
- Demonstrate the overall lifecycle benefit, such as higher production impact couple with a lower use phase.

- When used in combination in these and other ways the outputs of each could be enhanced.

Using LCA thinking in Supply Chain Risk Evaluation

A further way in which these areas could be linked is by thinking beyond a single "materials risk" to a wider supply chain risk associated with a product. Criticality generally refers to the initial stages of material production (i.e. mining and sometimes refining). The consequent stages are not considered as these are generally beyond the scope of these studies. A broader analysis would take into account various aspects of a product's supply chain, and LCA thinking could be used to enhance this approach.

A schematic of simple supply chain for a product is show in Figure 16.1. This can be viewed as representative of a product based on a metal, with a small number of mines, refiners and manufacturing sites. The product may be used in a large number of sites, though only a few options may be available for disposal. The solid lines represent the flow through the product's lifespan.

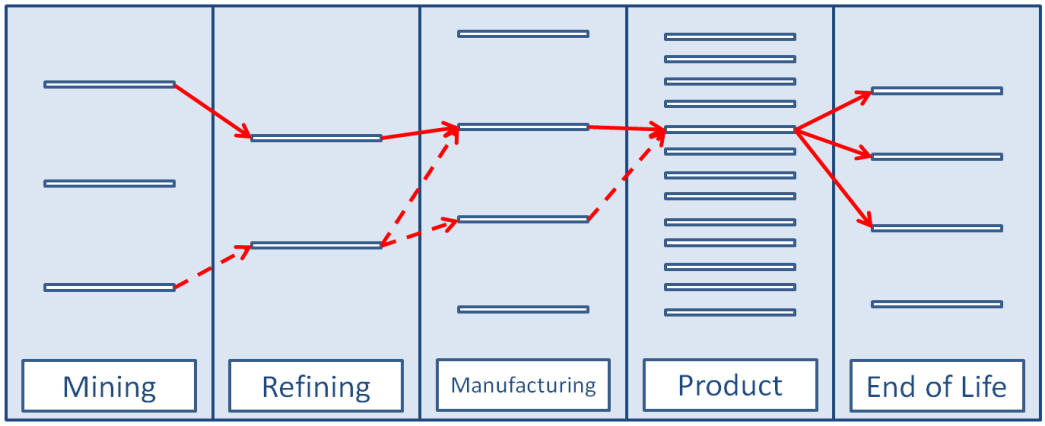

Figure 16.1 Supply chain schematic of a metal based product, reliant on a small number of miners and refiners.

In this circumstance the start of the supply chain is static and focussed in a small number of large production sites. It may be here that the greatest supply vulnerabilities exist, with only a handful of alternatives possible for these stages (dashed red lines). If this situation is compared to that presented in Figure 16.2 which is perhaps more representative of a textiles based product, differences in the supply chain are clear.

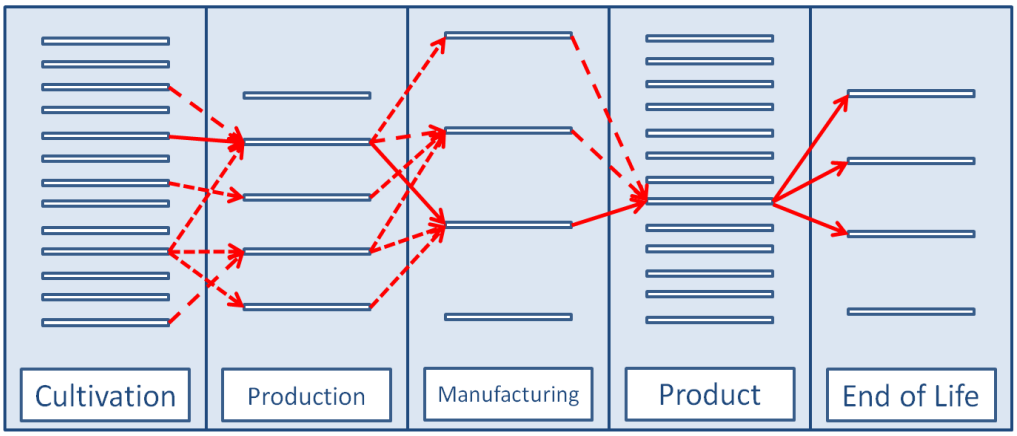

Figure 16.2 Supply chain schematic of a textile product, with many options for cultivation and production

The solid red line represents one possible route for a flow through the supply however there are many more alternative routes for a product to be produced, depicted by the dashed lines. Access to

the raw materials may be considered less of a risk than the example above, and manufacturing sites may pose the greatest risk. Similarly in cases where specialist manufacturing facilities are required the greater risk to access lies further along the supply chain rather than in the materials production.

Extending the consideration of criticality or risk beyond the materials phase could yield important results, such as understanding high concentrations of manufacturing capacity or flexibility of the supply chain for a product. This would allow analysis beyond a single issue risk to a wider supply chain risk. Using LCA type thinking to assist this process could be one approach to this analysis. Ideas such as functional unit, system boundaries, hot spots and indicators may transfer across to provide a robust, systematic and broad analysis.

Here two proposals have been put forward for bringing together LCA thinking and materials security (or criticality). This discussion has focussed on enhancing aspects of materials criticality and supply chain risk assessment. Direct incorporation of materials criticality indicator into LCA methodology is discussed elsewhere.

17. DISCUSSION

SECURITY OF SUPPLY AND SCARCITY OF RAW MATERIALS: TOWARDS A METHODOLOGICAL FRAMEWORK FOR SUSTAINABILITY ASSESSMENT

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17.1. IMPACT ASSESSMENT METHODS IN LIFE CYCLE ASSESSMENT

Life Cycle Assessment (LCA) is an internationally standardised methodology for the assessment of resource use and emissions that are associated with the supply, use, and end-of-life management of products, both goods and services. After compilation, the emissions and resource use inventory is analysed with the aid of impact indicators. These are broadly classified into Areas of Protection, commonly Ecosystems, Health, and Resources. Focus here was on the indicators provided in the context of Resources, where these had been identified prior to this workshop to be unclear in terms of how effectively they support stakeholders in their decision making processes and in relation to some business/policy priorities.

In the Life Cycle Impact assessment (LCIA) stage, one of the first steps after having selected the relevant impact categories is to assign inventory results to the selected impact categories. This step is called classification. Natural resources are typically grouped in categories such as biotic and abiotic, and/or renewable and non-renewable before being assessed.

The scope of the workshop was mainly on abiotic resources, and in particular on how to deal with raw materials. For this reason, resources like water and food stocks (e.g. wild fish) were not addressed. Nevertheless, some conclusions of this workshop may be relevant for a broad range of resource types.

In the context of abiotic resources, resource depletion is one of the most commonly considered indicators for Resources in current practice. The depletion indicator reflects the current availability of resources against their consumption (extraction) rates. Generally, the availability of resources is calculated taking into account e.g. reserves. The indicator often reflects the status of depletion of the resource compared to its reserves

At present, there are several methods and indicators available for resource depletion in the Life Cycle Assessment (LCA) Framework. As pointed out by Sala in section 6 each method has a different coverage in terms of number of resources included and the basis adopted for calculations can vary.

Only a few methods have a broad coverage of materials identified as being critical in terms of risks related to their security of supply (see section 6, tables 6.1 and 6.2); which may not be surprising, as focus is more on resource availability than security of supply in broader terms.

After having analysed the existing impact assessment methods against a set of criteria, the European Commission recently issued a report providing recommendations on the most appropriate method per impact category (EC - European Commission 2011a). These recommendations have been produced in order to foster reproducibility and comparability of results especially in those application contexts where it is vital to ensure the same level playing field among participants (e.g. organizations engaged in environmental communication; consultants providing advice to policy makers).

Natural resource indicators refer to two classes (i.e. minerals and fossils, and water) and the following methods were selected as the most appropriate for the European context at the time of the analysis:

- CML-IA (van Oers et al. 2002), measuring the use of minerals and fossils in terms of kg antimony (Sb) equivalent;
- (Frischknecht et al. 2008) measuring water use in terms of m3 related to local scarcity of water

Currently, the CML-IA resource depletion method comes out with a resource scarcity indicator covering 13 critical raw materials out of the 14 identified by the Commission (EC - European Commission 2010). The CML-IA indicator is thus not fully comprehensive. In addition, the approach taken does not mirror all criteria in the critical raw material assessment methodologies. The indicators, hence, primarily reflect relative importance in terms of resource availability insights and not in terms of security of supply considerations in a more general sense.

Ponsioen presented the latest developments in the context of the European Framework Project LC-IMPACT (section 7). He pointed out that none of the existing methods (CML-IA included) address topics such as e.g. geopolitical effects on security of supply normally addressed by methodologies for critical raw material assessment. For this reason, none of the resource scarcity indicators is suitable at present for assessing material criticality in LCA from e.g. this project. The public consultation at the start of the LC-IMPACT project resulted in recommendations for three types of indicators for abiotic resources (both minerals and fossils) using different time horizons: the long term focuses on overall availability (depletion), the midterm on the increase in effort for the extraction; the short term focuses on the availability depending on political factors (criticality).

How to best develop life cycle impact assessment methods for resource depletion assessment remains, however, a controversial task. Depending on the application context as well as on the goal of the study concerned, diverse classes of resources might be investigated and, thus, different methods might suit for answering diverse questions. A key issue is, hence, to make sure that mainstream methods and indicators support the main questions being asked by business and governments. Some argue that current indicators do not achieve this and their relevance in current practice remains limited. For instance, security of supplies is too often overlooked by mainstream methods.

Moreover, the issues of concern related to resource can vary from one type of resource to another. As pointed out by Drielsma, in fact, while fossil fuels are exhausted during combustion processes (thus a sort of depletion occurs in reality), most mineral resources remain in the anthroposphere. The high recycling potential of e.g. metals when associated with systematic collection can alleviate/prevent resource scarcity issues and should be taken into account when assessing the impact of resource use. During the workshop was reiterated several times that the landfill sites of today may be the mines of tomorrow. So, in theory, mineral resources could be continually recycled over time. Yet, for cases where mineral resources have a dissipative use (e.g. metals mixed to produce alloys), no full recovery of the original resources seems less possible and overall reduction of available stocks can therefore take place.

Two different perspectives emerged from the discussion on the concept of mineral resource scarcity. While, according to some, scarcity is mainly an economic issue, and technology innovation and resource prices regulates the trends in consumption and drive towards the substitution of scarce resources, others outlined the environmental impacts linked with the extraction of scarce resources, i.e. mainly the increasing of greenhouse gases emissions, energy consumption and wastes rock generation. Yellishetty showed how these aspects are correlated with decreasing ore grades and he argued that future constraints related to resources will be related to environmental problems (section 9).

There was instead a broad consensus among the workshop participants in proposing changes to the current scope of abiotic resource depletion assessment methods in LCA and in considering separately the different dimensions of resources: scarcity, depletion and criticality, as suggested by Van der Voet (section 5).

A further issue emerged in this discussion, regarding the appropriateness of considering resource depletion as an environmental aspect and within the environmental assessment. It was recognized that in the case of minerals the displacement of materials from their original place to other location and processes does not represent, by itself, an environmental problem. Since the impacts on environment and human health effects deriving by the extraction, refining, transport and other phases of resource use are accounted in the corresponding areas of protection, the resource depletion affects mainly the human societies rather than the natural ecosystems or health. It was, hence, suggested to avoid potential double counting when interpreting the meaning of Resource-related indicators. Nevertheless, although beyond the scope of this workshop, it was noted that this assertion cannot be generalized for all types of resources. It is, in fact, obvious that e.g. freshwater shortage in lakes and rivers may harm ecosystem services and even lead to biodiversity loss. Sala outlined that even within the mineral resources the effects on the ecosystems of the resource extraction can vary, depending on the type of resources, and its role in the biogeochemical cycles; these may not be well captured under indicators related to environment and health impacts in LCA.

The estimation of mineral resource availability was also extensively debated. It was outlined the exponential growing of mineral production and the declining trend of ore grades. At the same time, the statistics on mineral reserves depend on the current level of mineral exploration and undiscovered reserves could affect considerably on current availability. This further raised questions about the nature of current indicators considered in LCA for Resources. As suggested by Mr Drielsma during the workshop, reserves data are an aggregated indicator of the current supply capacity. They can be limited to those resources that have been proven to be profitable supply

options. LCA indicators based on reserves data therefore have some socio-economic and geopolitical factors built in to them. For the same reason, the current indicators provide an immediate snapshot of depletion potential and may say little about the potential to deplete the total stock of natural resources. There followed some discussion on how to best reflect this to stakeholders when considering the results of assessments.

Having discussed extensively the nature of current recommended indicators in LCA, while arguably in the context of this question, the broader issue of whether resource-related considerations should be considered in LCA, and particularly issues of security-of-supply, were addressed under the subsequent question on "How (and if) supply risk should be included in LCA?".

17.2. DEFINING CRITICALITY: METHODOLOGICAL IMPROVEMENTS IN THE IDENTIFICATION OF CRITICAL RAW MATERIALS

Two complementary approaches were presented by speakers for CRM assessment, namely a top-down approach, i.e. having as a reference subject the whole economy, and a bottom-up approach, taking into account the interests of e.g. a single economic sector. One example of the top-down approach was presented by Malwina Nowakowska, who illustrated how the critical materials for the European economy have been identified (EC - European Commission 2010a).

Two methodologies for the identification of CRM for the energy sector and using a bottom-up approach have been presented by Vangelis Tzimas (section 12) and Paul Telleen (section 13) through a pre-recorded presentation (US Department of Energy 2010). Tzimas displayed a case study in which the potential bottlenecks for the deployment of low carbon energy technology due to shortages of materials have been assessed. The materials' demand estimates and the supply projections have been compared for estimating the future materials availability (Moss et al. 2011; Moss et al. 2013). The US Department of Energy's (DOE) Critical Material Strategy presented by Mr Telleen has a similar approach, aiming at informing policy makers and the public on potential criticalities.

The overview on different methodologies for criticality assessment showed that, irrespective of the specific methodology adopted, results are often similar. This was pointed out when the results of the CRM assessment for the EU were compared with those for the US economy. This happens because CRM assessment methodologies normally touch upon very similar aspects, although not always the same. The main aspects considered include the importance of the material (for the economy or for a sector/activity) and the risk of supply disruptions. Environmental aspects related to resource use as well as resource depletion have instead a different consideration in the two methodologies.

Sievers pointed out that criticality has multiple aspects, depending not only on the security of supply but related also to social and environmental risks associated with raw materials, which include the conflicts related to mineral production and the physical availability of resources, with respect to the demand trend.

Tercero Espinoza provided a broad overview of the features of CRM assessment methodologies (section 14). It was stressed that criticality is a relative concept and, as such, it cannot be assessed without having a frame of reference. This frame is based on the thresholds set for those indicators defining what materials are critical. These thresholds are based on political or business decisions and, because of their nature, it is rather difficult to mix them with other environmental indicators.

From a risk analysis perspective, the two dimensions taken into account in CRM assessment methodologies represent how likely is the event to take place (risk) and the impact magnitude, namely how large would be the impact of such event (importance).

In CRM assessments, the risk dimension is represented by the risk of a supply shortage. In the EU methodology for CRM assessment, political aspects are embodied in the risk dimension. The impact magnitude dimension is interpreted either by the negative economic impact of a shortage or the economic importance of a raw material to an economy.

Depending on the scale (e.g. country, region, sector, individual companies), relevant dimensions can be defined for CRM assessments.

Criticality assessment results change over time and space. For this reason, they are a snapshot of the business-as-usual scenario.

The discussion was quite extensive during the workshop on how to best integrate CRM results in LCA assessments.

Many participants stressed the role of CRM assessments to provide decision makers with early warning to track changes in criticality over time. If integrated in LCA (e.g. via a life cycle impact indicator), early warning could be set at different levels such as EU or sectorial. This may, hence, need to be defined more precisely when considering specific product groups or sectors in e.g. category rules (i.e. in the rules generally defined by stakeholders to help focus assessments on hotspots in supply chains and in relation to which pressures to consider rather than always conducting general assessments).

During the workshop, the potential benefit of an international common database for CRM assessments was reiterated several times. This would allow different countries to come to the conclusions on a similar basis; while such conclusions may necessarily differ depending on what sectors are more important in a given economy. Nevertheless, it was argued that there is no international consensus on issues such as e.g. political stability in certain countries and, for this reason, it would be hard setting up a unique common database which is widely accepted by all countries worldwide. Internally consistent databases could be set up in cooperation with countries sharing the same views.

Given the limited scope of environmental information of critical raw material supply (often from-cradle-to-gate with possible extension to material end-of-life), different points of view emerged among participants on if and how the environmental dimension should be kept in the CRM assessment.

A few participants argued that environmental information are to be kept out the CRM assessment and should be reported separately. It was highlighted that often the environmental status of different countries was analogous to their political stability; hence correlated. Indeed, when considering an LCA, integration of environmental information (e.g. recycling rates of materials) in CRM assessments would create “double-counting” or bias when then presenting results as separate environmental indicators.

Saveyn presented some JRC-IPTS' existing activities on techno-environmental modelling and policy support. In particular they are developing a ready to use model for quantification of changing environmental-economic impacts related to a change in effective prevention, reuse and recycling of materials. The developed model and indicators have been applied on two case studies (a classic waste material and a CRM).

17.3. RESOURCE SECURITY IN SUSTAINABILITY ASSESSMENT

Schneider presented the on-going work on material scarcity assessment at the TU Berlin (section 8). Several single indicators were proposed to address supply risk in the broader Life Cycle Sustainability Assessment. These indicators, mostly having economic nature, focus on selected aspects of supply risk such as e.g. concentration of resources (in terms of reserves) per country, political stability, concentration of extraction activity per company, secondary production (recycled

content), trade barriers, material substitution, companion metal fraction, anthropogenic reserves, and expected growth in demand.

On day 2, Vieira scanned with workshop participants which elements should be captured when setting up LCA methods for abiotic resource assessment (section 15). It was acknowledged that resource supply risk is a major issue for policy makers and industries, especially when they have to deal with strategic decisions. In LCA, some pointed out that the assessment of resources such as fossils and minerals was initially considered in the life cycle impact assessment framework because human activities cause decrease in resource availability for future generations. According to Vieira, the principal components to capture are the following: recyclability, technological development, population and economic growth, and substitution.

It was discussed if security-of-supply issues should be assessed in LCA, or in a social-LCA.

Several of the participants agreed that LCA should capture material criticality in order to drive business and policy strategies towards sustainability. Some remarked that LCA is an environmental assessment framework and, hence per definition, such issues should be left out. Others highlighted, however, that LCA already addresses the Area of Protection "Resources", although not as an environmental issue per se, and thus the additional effort needed to bring criticality assessment in the LCIA would be minimum.

This opened the doors to a thorough discussion on the actual intrinsic nature of LCA. It was suggested that LCA is not just an environmental assessment methodology, but LCA is rather a framework facilitating the sustainability assessment of pressures or burdens of whatsoever nature associated with emissions and with resources consumed in product life cycles. Given that the LCA impact assessment framework already goes much beyond the environmental pillar of sustainability (see e.g. the impact of water footprint and global warming often used as proxies for impacts on society and economy), it was proposed to redefine LCA in the context of the broader Life Cycle Sustainability Assessment. It was also highlighted that social LCA may not focus on resource use and emissions inventories; hence may not be appropriate for assessing resource-use pressures that are currently addressed in LCA.

It was concluded that, even if the use of critical raw materials does not constitute an environmental issue per se, the current framework of LCA, accounting inputs and outputs in the supply chain, could be readily used to analyse the use of CRM along the life cycle, while the potential inclusion in LC impact assessment requires further investigation and development.

During the workshop the different natures of LCA and methodologies for assessing criticality were highlighted: while the former is based mainly on quantitative data, the latter underpins on a relative concept (critical to whom? Where? When?), has some elements of subjectivity (e.g. set of thresholds) and can be considered as a kind of risk assessment. In his presentation Chapman discussed these issues (section 16) which lead to the conclusion that also LCA assesses risk factors. For instance, it was mentioned how human toxicity indicators normally reflect e.g. the risk of getting cancer on the basis of the average exposure to pollutant pressures. For this reason, LCA does not only assess what impacts will certainly take place, but already assesses what is likely to occur in some cases. It was highlighted that the indicators in LCAs are, furthermore, very different in scope depending on the impact category being assessed (some related to risk, some to impacts, some providing additional information such as was argued to be the case for resource indicators related to scarcity and for non-cancer effects for human health). On this basis, there was some consensus that LCA, integrated into a broader Life Cycle Sustainability Assessment framework, could be used to assess the risk associated with resource supply. It was also notable that combining indicators in LCAs using e.g. weighting may be a very questionable practice due to the different nature of the indicators for each impact category.

Rather than developing new methods for addressing CRM assessment in LCA, it was proposed by some to rely on the outcomes of governmental critical raw material assessments. More specifically,

it was proposed to report critical raw material use in different LCAs, if any, based on the resource-use inventory data. This may be an initial, easy-to-implement approach in current LCA practice.

At the microeconomics level, this piece of information may be used by organisations in the early stages of design processes of products/systems, to enhance ecodesign. For example, the use of CRMs might be reduced or avoided by designers when considering supply chains, either by optimization or by substitution. Alternatively, the use of CRMs could be addressed during design via dedicated ecodesign strategies, including design for dismantling of key components, thus facilitating the end-of-life management and the recovery of such components/materials. Information on the quantity of CRM in typical applications/products might also be shared by manufacturers to recyclers, so that appropriate recovery technologies can be developed.

At the macro scale, life cycle based sectorial indicators could also help governments better identify where critical raw materials are used in relation to their economies and associated supply chains and end-of-life management practices.

To allow LCA practitioners to report additional information on CRMs at the inventory level, the relevant databases on CRMs should be regularly updated and spatially resolved. What is critical today, in fact, does not likely match with what may be critical tomorrow. Similarly, what is critical in a country does not necessarily match with what is critical in another. Certain reserves may be located in only very few specific geographical areas worldwide. Hence, internationally agreed indicators in this context may be hard to achieve; unless a list is compiled taking into account different national lists of critical raw materials and used in the LCA context.

As CRM lists can differ when assessed at e.g. national vs. sectorial level, the issue of CRMs in an LCA might be addressed at also e.g. the sectorial or product group levels. For instance, the European policy related to sustainability assessment of construction materials was mentioned and the need to perhaps have a list related to the construction sector developed through product-specific rules.

In the context of the European Commission's Environmental Footprint recommendations, reporting material criticality information might be recommended in product-specific guidance (i.e. Product Environmental Footprint Category Rules – PEFCRs) or organisation type-specific guides (i.e. Organization Environmental Footprint Category Rules – OEFCRs) (EC - European Commission 2013).

18. CONCLUSIONS

The workshop "Security of supply and scarcity of raw materials: a methodological framework for sustainability assessment" gathered together different stakeholders (from academia, industry, consultancy and government) and two different scientific communities (from sustainability assessment and from criticality assessment) to discuss the potential of supply chain analysis in supporting a resource policy. In particular, it questioned if and how the systematic consideration of CRM in LCA would provide policy makers and industry with more relevant information on how to manage CRM more efficiently, and how to combine resource security strategies within sustainability assessments.

There was a broad consensus within the workshop participants in recognizing that current indicators for resources in LCA have strong limitations and that different aspects related to resources should be taken into account, in addition to scarcity.

The different nature of LCA and criticality assessment methodologies has been extensively discussed during the workshop, as well as the appropriateness of considering resource-related aspects within the LCA framework. It was proposed that LCA is a methodology to assess the potential pressures of resources used and emissions; not only environmental impacts.

It was also highlighted that the different nature of impact assessment results in LCAs must be more transparent. Methods such as weighting may be misleading due to the different pressure, risk, and impact nature of the different indicators in an LCA.

Criticality can be readily assessed in existing LCA practice using e.g. available criticality lists, while other, more advanced methods may be developed. Nevertheless, a single international list may be hard to define due to the difference in economies and what is nationally critical. Equally, lists of critical materials can vary by sector; suggesting generic lists may require adaptation at the product-group specific assessment level and inclusion of different lists in product-group specific life cycle guidelines.

It was concluded that a re-design of the impact assessment methods for resources in LCA is needed, and that it should not be limited to depletion aspects. It was also acknowledged that LCA has a potential for managing risk related to resources and that information on materials' criticality could be easily used at inventory level for identifying the flows of CRM in supply chain, minimizing their use and fostering their substitution.

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Abstract

The security of supply of raw materials has become a high-priority theme in the political agenda of the European Union (EU). The European Commission has started to take action in order to ensure access to resources and avoid supply shortages. Critical Raw Materials (CRMs) have been identified with the aim of helping to anticipate/prevent supply shortages. Supply chain analysis could be used to detect and signal the use of CRMs in order to enhance the efficiency in their use, facilitate their proper end of life management, speed up their substitution and provide policy makers with proper information.
The scope of the JRC workshop "Security of supply and scarcity of raw materials - A methodological framework for sustainability assessment" was to review the methodologies of impact assessment for resources in Life Cycle Assessment (LCA) and the ones for CRMs identification in order to shed light on the supply chain analysis potential in supporting resource policy. The inclusion of supply risk-related aspects in LCA deserves further investigation and development. It was concluded that LCA has a potential for managing risks related to resources in the context of sustainability assessment.

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