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Abiotic resource use in life cycle impact assessment—Part I- towards a common perspective

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ABSTRACT

At the beginning of the SUPRIM project, there was no global consensus on the assessment of impacts from the use of abiotic resources (minerals and metals), in life cycle impact assessment (LCIA). Unlike with other impact categories such as global warming, there is not just one single, explicitly agreed-upon problem arising from the use of abiotic resources. The topic is complex and new methods are still being developed, all with different perspectives and views on resource use. For this reason, the SUPRIM project initiated a consensus process together with members from the research and mining communities, with the aim to obtain an understanding of different stakeholders' views and concerns regarding potential issues resulting from the use of resources. This paper reports on this consensus process and its outcomes. Insights from this process are twofold: First, the outcome of the process is a clear definition of the perspectives on abiotic resources which form the starting point to further refine or develop LCIA methods on abiotic resource use. Second, the process itself has been a challenging but valuable exercise, which can inspire the evolution of other complex issues in life cycle impact assessment, where research communities face similar issues as experienced with abiotic resources (e.g. water and land use, social LCA, etc.).

1. Introduction

Life cycle assessment is an established technique used to evaluate environmental impacts of products and processes; and there is a good level of consensus on many life cycle impact assessment (LCIA) methods today. However, for abiotic resources, which include minerals and metals, simply referred to as 'resources' in this manuscript, methods dealing with the depletion of geological stocks have been criticized by representatives of the metals & mining industries. Therefore, the Life Cycle Assessment (LCA) community has been developing a number of new, but divergent methods, which all focus on different issues related to resource use (Sonderegger et al., 2017).

This lack of a broadly accepted method and the ongoing development of new methods are likely attributable to the lack of a common perspective on resource use, and a common understanding of the potential problem(s) related to the use of resources. This was the starting point of the SUPRIM project.[1] The acronym stands for Sustainable Management of Primary Raw Materials through a better approach in Life Cycle Sustainability Assessment. The aim of SUPRIM was to obtain an understanding of different stakeholders' views and concerns regarding potential issues which result from the use of resources, and to use the insights for the development of an LCIA method that reflects these concerns. In general, a consensus on LCIA methods is important when LCA studies are conducted in a product- or corporate benchmarking or policy context (Jolliet et al., 2014). The LCA community organizes consensus-finding processes for impact assessment methods by means of working groups consisting of voluntary experts from the respective research fields, which aim to build scientific consensus on environmental LCIA indicators (Frischknecht et al., 2016; UN Environment, 2019). This is achieved by means of virtual meetings and stakeholder workshops. In parallel (and in collaboration) with the SUPRIM project, efforts towards a harmonization of LCIA for natural resources were undertaken by the Task force on mineral resources of the Life Cycle Initiative hosted by UN Environment (Task Force Mineral Resources) during the years 2015-2018. Given the variety of perspectives on resource use (Ali et al., 2017; Dewulf et al., 2015; Giurco et al.,

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[1] http://suprim.eitrawmaterials.eu/about-project.

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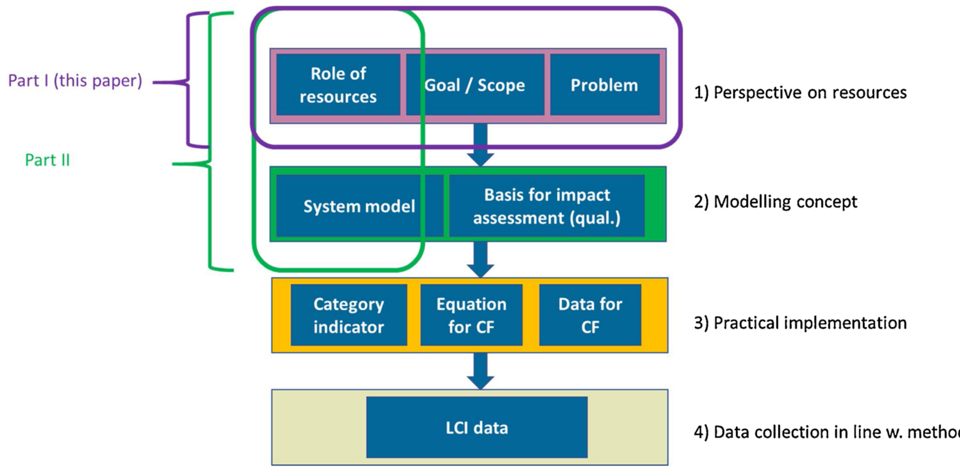

Fig. 1. Framework for analysis (and development) of LCIA methods, and other approaches to modelling the use of abiotic resources (minerals and metals), and relevant aspects in this paper.

2014; van Oers and Guinée, 2016; Sonderegger et al., 2017), and the complexity this brings to the development of LCIA methods for this topic, a thorough discussion of the underlying aims and strategy to the management of resources seemed necessary. The SURPIM project therefore tackled the issue by 'taking a step back' and initiating a structured discussion about potential problems with resource use, and different motivations behind resource management concepts. To overcome the difference in views on sustainability and resources held by the mining industry and LCA community (Freitas de Alvarenga et al., 2019; Gorman and Dzombak, 2018), a special focus was put on enabling discussions between those two groups.

Stakeholder consensus processes can take various forms. They may involve face-to-face meetings with informed and in-depth discussions on the topic at hand (Innes, 1996), or a combination of different methods, including literature reviews, surveys and face-to-face meetings (Devane et al., 2019). A recent meta-analytical study on consensus-orientented decision making identified a number of factors as crucial to the success of these consensus processes, including a face-to-face dialogue, trust building, and the development of commitment and shared understanding (Ansell and Gash, 2008).

This paper is the first part of a two-part submission. It outlines the steps undertaken in the SUPRIM consensus finding process, conducted with the help of a multi-level framework created to guide the process, and presents its outcome: the definition of perspectives used as a basis for further method development in the project. Part II to this publication has been submitted to this journal in parallel by the same project team (Schulze et al., 2019, submitted). In Part II, the linkages between the perspectives on abiotic resource use taken by the LCIA method developers and the models they use are analysed. That analysis is done with the help of the same framework.

With this paper (Part I), focusing on the consensus process, we aim to contribute to two different fields of knowledge. First, the outcome of the process is a clear definition of the perspectives on resource use. This outcome is expected to be useful to other researchers working on the development of LCIA methods on resource use. It also provides the basis for the understanding of the methods to be developed by the SUPRIM team in particular. Second, the consensus-finding process itself can inspire the evolution of other complex issues in LCIA, where research communities face issues similar to those experienced with abiotic resources. As part of the discussion to this paper, we provide an outlook to other topics of LCIA where we believe such a process could be beneficial.

2. The process

Below, we outline the consensus process undertaken in SUPRIM and its outcomes: the definition of the perspectives on resources for use as a starting point to develop methods later on in the project. To begin with, a literature review was conducted to gain an overview of current discussions on LCIA of abiotic resource use. Using the insights, a framework was developed to guide a structured discussion with stakeholders on the perspectives on resource use. This discussion took place in the form of a workshop with external stakeholders, during which the most commonly preferred perspective type was established.

2.1. Outlining a framework

Prior to the stakeholder workshop, participants were contacted and informed of the topic by means of a workshop input paper. For this purpose, a framework was developed which would enable a structured discussion on the complex, multifaceted issue of resource use. The framework is the result of an effort to organize a number of relevant questions into a logical structure. It was created in a way that is open and capable of reflecting a large range of possible perspectives on resources. Furthermore, the workshop participants were invited to provide answers which go beyond the questions provided by the framework structure in order not to restrict or cut-off any possible views. The framework consists of (1) an overarching perspective, (2) a conceptual level ("Modelling Concept") and (3) a practical implementation level (Fig. 1). Level 4 is not part of the method development process as such, but has been included in the framework to emphasize that the life cycle inventory data collection needs to be aligned with the respective LCIA method. This section outlines the idea of the framework which is being used in SUPRIM. Level one of the framework concerns the perspective on resources. It is detailed in Section 2.1.1, and is the most relevant level for the consensus process described in this paper.

2.1.1. Level 1: perspective on resources

Level 1 of the framework asks why resource use is of concern. and thereby clarifies which perspective on resources is taken. It does so by introducing three criteria to define the perspective on resource use: "role", "goal & scope" and "problem". A basic requirement for the definition of a perspective on resources is an understanding of the resource use (& supply) system currently in place, as well as its societal and environmental benefits and challenges.

2.1.1.1. Role. Abiotic resources can be valued for different reasons, ranging from a (conservationist) value of the resource per se, to ecosystem functions (e.g. soil formation and nutrient cycling), to their role in the economy. It is therefore important to clarify the role and context in which they are seen. The 'role' of resources explains the motivation behind protecting the resources – see also Dewulf et al. (2015). The role is defined as the context in which the resources are valued - in relation to

- the stakeholder 'interested' in the resources, i.e. either humans, the environment, or the resources themselves
- the system of concern in which the resources and/or their functions are valued (e.g. environment or economy), and
- the relevant production system (primary, or primary and secondary production).

When used in combination, the three criteria on the role of resources clearly define who is motivated to protect or maintain the resources, which system (environment or economy) they are valued in, and which system they originate from (the primary, or both the primary and the secondary production system). Since they clarify the overarching strategic perspectives, the definition of the 'role of resources' can be used to classify resource management concepts and impact assessment methods. The combinations are therefore also referred to as 'perspective types' Through the definition of distinctive answers given above, a list of possible combinations can be provided (Table 1), not all of which are equally meaningful, and some of which are difficult to interpret.

Combinations A–E (Fig. 2) may be particularly relevant and are therefore described as examples below:

Type A perspectives concern a human interest in resources obtained through primary production (e.g., mining and subsequent processing) for use in the economy, for example, primary aluminium which is mined to manufacture a window frame. Type B perspectives differ from Type A perspectives in that the aluminium produced from secondary sources (through recycling) is valued as well as that from primary production. Type C perspectives concern the role of abiotic resources in ecosystem functions, e.g. filtering of water, soil formation etc. Type D perspectives consider both the functions valued under Type A and Type C perspectives at the same time. For example, in the case of sand and gravel, the role of the resources in the economy as a building material is valued as well as their role in the natural environment (e.g. seabed or beach). Type E perspectives are very abstract and included here for the sake of completeness and differentiation only. Sometimes, the latter are also associated with the term 'intrinsic value' (of the resources). Perspective Types A–E are elaborated in more detail in Part II of this submission.

2.1.1.2. Goal and scope. Furthermore, as part of the definition of the perspective, the goal with regards to resource use needs to be defined. For example, the goal may be to ensure the continued accessibility of resources in the economy, or to balance their accessibility in environment and economy (see SI Table 1 for a detailed clarification of the term accessibility as used in SUPRIM). In brief, availability concerns the physical presence of a resource, and accessibility concerns the ability to make use of a resource. Resource management concepts differ in terms of goals. To illustrate this point, the following example is provided: When focusing on critical resources, the goal is to prevent supply disruptions, or to reduce supply risks. This can be achieved in different ways such as a demand reduction through substitution efforts for critical metals, or investments into new mining projects. Here, the goal is not necessarily a reduction of the primary production output. However, resource management concepts concerned with a finite resource stock in the environment usually aim at a delay or reduction of primary production output.

The criterion 'goal' is closely related to the role of resources, but more specific; i.e. for each perspective type ("role of resources") defined, the definition of one or more goals is possible. The goal is defined in scope, which comprises a time perspective, a geographical perspective (e.g. global, European), and the types of resources covered by the assessment (e.g. elements, and/or minerals, natural stone). The time perspective clarifies to what extent the interests of future generations are considered, and how future interests are to be balanced against current interests – see e.g. Goedkoop et al. (2009), Hellweg et al. (2003). The time perspective also has further implications for the scope of resources to be covered, and later, for the data used to determine the relative impact of different resource flows.

2.1.1.3. Problem. The problem describes what prevents the defined goal from being achieved. In broad terms, it concerns the increased difficulties which people may face with regards to the use of a resource, i.e. that when using a resource, it is temporarily or permanently unavailable for the purpose(s) considered. The problem definition can (not exhaustively) concern:

- a permanent, irreversible loss of a resource from a certain system as a consequence of its removal from that system (e.g. the removal of resources in their original form from the environment)
- the destruction of useful/ valued properties (exergy, mineral structure, concentration of target metal) or

Table 1
Eighteen 'perspective types', based on all possible combinations of the 'role of resources'.

Combination	Stakeholder Who is interested	System of concern System where they are valued	Production System Source for production	Perspective Types, based on role of resources
1	Human	Economy	Primary	A
2	Human	Economy	Primary & Secondary	B
3	Human	Environment	Primary	C
4	Human	Environment & Economy	Primary	D
5	Resource	Environment	Primary	E
6	Resource	Economy	Primary & Secondary	F
7	Human	Environment	Primary & Secondary	G
8	Human	Environment & Economy	Primary & Secondary	H
9	Resource	Economy	Primary	I
10	Resource	Environment & Economy	Primary	J
11	Resource	Environment	Primary & Secondary	K
12	Resource	Environment & Economy	Primary & Secondary	L
13	Environment	Environment	Primary	M
14	Environment	Economy	Primary	N
15	Environment	Environment & Economy	Primary	O
16	Environment	Environment	Primary & Secondary	P
17	Environment	Economy	Primary & Secondary	Q
18	Environment	Environment & Economy	Primary & Secondary	R

A. abiotic resources are valued by **humans** for their functions used (by humans) **in the economy**, **primary production only**

B. abiotic resources are valued by **humans** for their functions used (by humans) **in the economy**, **primary and secondary production**

C. abiotic resources are valued by **humans** for their in-situ functions **in the environment**, **primary production only**

D. abiotic resources are valued by **humans** for their functions in the **economy** and their in-situ functions **in the environment** considered useful to humans, **primary production only**

E. abiotic **resources** are valued for their own sake **in the environment**, regardless of their usefulness in environment or economy, **primary production only**

Fig. 2. Five different perspective types ("roles") of resources.

- a change in accessibility of the resource.

The consideration of an absolute loss is linked to an assumption of a fixed stock of resources. The stock can be defined by the presence of the resources in the "system of concern" where their functions are valued, its accessibility in that system, its accessibility to the relevant production system[2] or indirectly through a property which is considered beneficial (e.g. exergy, presence of certain metals in the ores). The property-based definition of the stock can be linked to a system (environment or economy), combining both criteria - e.g. through a minimum concentration of an element in the ore, i.e. in the environment, at relevant volumes.

2.1.2. Level 2: modelling concept

Level 2 of the framework, which is referred to as 'the modelling concept', comprises the system model and the basis for impact assessment of using one resource compared to another.

The system model is an illustration of how resource stocks and flows are positioned with regards to the environment and economy. For example, the stocks may be positioned within the environment and the flows may be located between environment and economy. The illustration defines the life cycle inventory flows which the impact assessment is based on, and, at the same time, illustrates which flows and stocks need to be considered in the characterization model. For logical consistency, the positioning of the stocks relevant to the LCIA model should match the position of the flows of the LCI model and, at the same time, reflect the role of resources, and the goal and scope definition. To give an example: If the depletion of geological stocks of resources is the prime concern, it makes sense to base the model on resource flows from the environment to the economy. If, however, a stock of primary *and* secondary sources is the matter of concern, those flows may no longer be relevant, and a different system model would be required (see also Part II to this paper).

The 'basis for impact assessment' refers to the criterion according to which the use of one resource is evaluated against the use of another. For example, the criterion might be mass, energy content or different kinds of costs associated with the resource flows. It is based on the potential of different resource flows to contribute to the considered impact category for the assessment of resource use. It is primarily a function of the problem definition, but also needs to be in accordance with the role, goal and scope defined as part of the perspective.

[2] In case of a model that assumes only primary production, the focus is on the presence of resources in the environment, since it is the environment that resources are taken from.

2.1.3. Level 3 and 4: practical implementation and data collection

At the third level, the i.e. the practical implementation level, the equation which specifies how the characterization factors are calculated is built in accordance with the modelling concept. Data is compiled for the characterization factors in line with the relevant flows defined in the system model and the scope of resources covered by the method. At the fourth level, life cycle inventories have to be compiled accordingly.

2.2. Defining the perspective

The task to define the problem was tackled by means of a workshop with external stakeholders with the aim to create a common understanding amongst the participants and their stakeholders of the perspectives on resource use and the potentially associated problem(s). The idea was to go "back to the drawing board" to understand the participants' views on the role(s) of abiotic resources that need protecting, and on the issues they thought needed to be managed. To obtain a thorough understanding, the participants were invited to share their knowledge regarding the resource use and supply system. The project's focus was on LCIA methods assessing the impacts associated with the (human) use of abiotic resources, and in particular, the dialogue between method developers and the mining industry to work towards a consensus regarding the application of life cycle impact assessment methods on resource use. This focus was chosen since mining industry representatives had previously engaged in a dialogue with the life cycle assessment community and had taken the role of the most interested, but also most critical stakeholders. Hence, the workshop participants were identified and selected to represent a mixture of stakeholders from industry, policy support, research institutes and academia, with the aim to achieve a balanced composition of participants with regards to their work experience in relation to both resources and LCIA. Some participants had a track record of developing and evaluating LCIA methods, and/ or were involved in the 'Task Force Mineral Resources'. Others had been involved in policy support regarding abiotic resources, had implemented LCIA methods in an industrial setting, were representatives of the mining industry or had backgrounds in geology. Other members from the resource supply chain (e.g. from the metal processing industry) were invited but could not attend. Although the number of workshop attendees had to be limited to a practical size for organizational reasons, opinions of interested non-attendees were also considered and included those of people not professionally engaged with resources.

The workshop was finally attended by 17 representatives from industry, industry associations, academia, research institutes and policy support, including partners from the SUPRIM project and invited

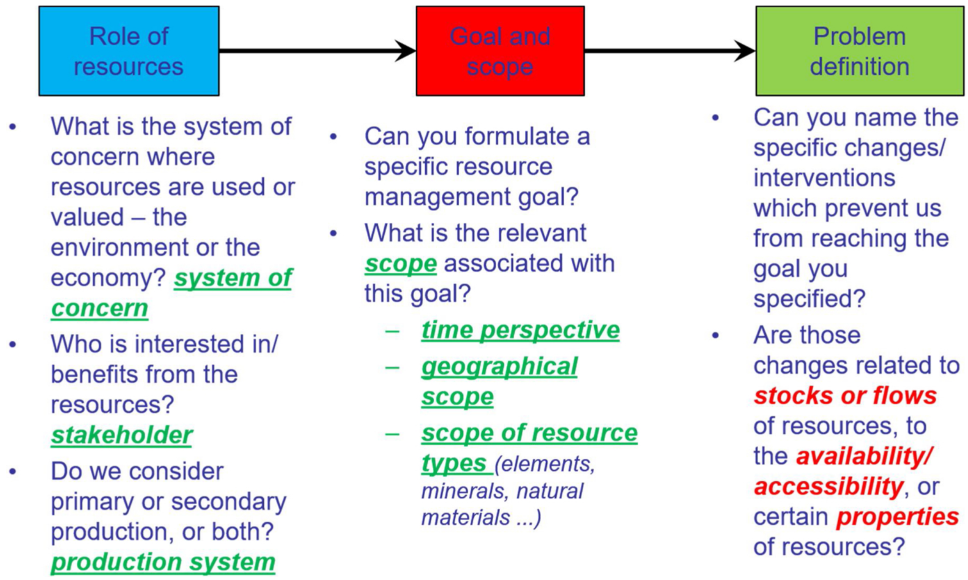

Fig. 3. Suggested criteria for the discussion on perspectives.

project-external stakeholders.

Prior to the workshop, participants were provided with an input paper introducing the topic and points for discussion. Participants were asked to answer the following two questions:

1 What, in your opinion, are the key issues of concern to be addressed when managing abiotic resources (minerals, metals, natural stone)?
2 Can and should these issues be addressed by LCIA methods, or would other tools be better suited?

Furthermore, the workshop input paper also introduced the framework to the workshop participants (2.1). Following the structure of the framework, for each role, there could be several goal and scope definitions. And then again, for each defined role-goal-scope combination, there could be several problem definitions. This 'openness' was addressed through the introduction of distinctive criteria at each level. Those are shown in Fig. 3. For example, for the role of resources, the criteria are stakeholder, system of concern and production system.

2.2.1. Choosing the role of resources

At the core of the workshop was a moderated discussion which aimed at finding a consensus on the different views and perspectives. The moderation focused on the two questions that had already been introduced in the workshop input paper (see section above). The discussion started by asking all workshop participants to formulate their own concerns related to resource use in response to question 1. The idea was that this question should be answered independent of any pre-defined perspectives, views on existing LCA methods, feasibility of addressing the issues in LCIA, etc., in order not to restrict the participants in their answers. Participants recorded their views on post-it notes. The moderators then ordered the thoughts on a whiteboard by common topics in order to identify themes of concern to the participants to be addressed in more detail in sub-group discussions. Ten themes were identified by the moderators. They included "availability and access", "sociopolitical risks", "economic issues", "resource quality aspects", "policy", "depletion", "environmental issues", "use/function", "knowledge and information", and "other". Participants were asked to place "voting stickers" onto the whiteboard, representing three possible votes for each theme: "already addressed in LCA" (blue stickers), "should not be addressed in LCA" (red stickers), "is not yet addressed in LCA, but should be" (yellow stickers). This was done in order to identify the themes which the participants considered relevant for coverage in LCA, but which were at the same time not yet well represented in LCIA.

The list was narrowed down to three themes to be covered during the group discussions: availability and access, depletion, and resource quality aspects. This was broadly based on the number of people who thought a topic was not currently covered in LCA, but should be (i.e., the number of yellow stickers assigned to one topic) (Table 2).[3] Participants were then split into three working groups and asked to reflect on these themes during group discussions, and to use the evaluation scheme provided in the workshop report (Fig. 3) to attempt the formulation of a common perspective within each working group. As a starting point for the discussions, an initial list of five perspective types identified in the workshop report was given as an input to the workshop participants (Fig. 2). The suggested perspective types were intentionally addressing very basic, general questions and thus were not intended to restrict, but to guide the consensus process.

The overall picture compiled as a result of the "brainstorm session" (i.e. the very open question about peoples' views on the key issues with resource use) provided some very diverse answers from individuals, likely due to differences in professional and personal backgrounds and views. The groups were given some time for discussion, during which they used the suggested criteria and questions presented in Fig. 3 as a guideline for a discussion on the perspectives of greatest interest and relevance. Furthermore, they reflected on the three focal topics identified during voting (Table 2) in order to come to a consensus regarding the key issues regarding resource use to be assessed in LCIA. After some time for discussion, each group presented the outcome of their discussion. The focus of the group discussions varied, but participants all agreed that one of the pre-defined perspective types presented in Fig. 2 should be given priority for further analysis, namely the Type B perspectives. The Type B perspectives focus on both primary and secondary resources used by humans in the economy. The Type B perspectives were adopted as a basis for further development of perspectives in SUPRIM. Besides the input given during the workshop, answers were received from other stakeholders who were unable to attend the workshop in person. The non-attendees mentioned the

[3] The topic "(lack of) knowledge and information" was not selected for the group discussions since it was considered more a common cause of concern about the other topics raised, rather than a topic of concern in its own right. The topic "depletion" was chosen instead, due to its high relevance in current discussions around life cycle impact assessment, and due to some of the participants suggesting that the topic was not yet appropriately covered in LCIA.

Table 2
Voting on topics of concern regarding resources during the stakeholder workshop (number of votes).

	availability and access	sociopolitical risks	resource quality aspects	policy	depletion	environmental issues	use/ function	knowledge and information	other	economic
already assessed in LCA					7	8	2			
should not be assessed in LCA	3	7		8	2		1	2	2	8
is not yet addressed in LCA, but should be	6		8		3			5		

increased demand for recycling or the potential consideration of secondary stock when assessing the impacts of resource use in LCIA, which might suggest a potential support for adopting the Type B perspective when assessing resource use in LCIA. Since all respondents had – as requested - discussed relevant issues within their organizations prior to the workshop, the consensus perspective could be considered to reflect more than the opinion of a small number of individuals. This was confirmed when it was subsequently endorsed by the UN Environment Life Cycle Initiative 'Task Force Mineral Resources', who used alignment with Type B perspectives as a criterion for its evaluation of LCIA methods and formulated a safeguard subject for mineral resources within the AoP natural resources based on this perspective (Berger et al., 2019; Sonderegger et al., 2019).

Looking back at Level 1 of the framework (Fig. 1), the workshop was only able to address the role of resources. Therefore, starting from the Type B perspective for the role of resources, the next task for the SUPRIM project team was to come up with a manageable number of goal and scope and problem definitions considered important and relevant to complete the perspective. However, it soon became clear that this was a challenging task. Several attempts had to be made for a consensus on the goal and scope, despite this step being tackled as a project-internal exercise. The process is outlined below.

2.2.2. Defining the goal and scope

2.2.2.1. Attempting a consistency- and relevance-based approach. At first, it was decided to tackle the challenge of the goal and s cope definition through a systematic exercise to be conducted by the SUPRIM project team. Starting from the criteria for the goal and scope definition previously communicated to the workshop participants (Fig. 3), the criteria were slightly refined: 2–3 distinctive possible answers were defined for each criterion (i.e. goal, resource scope, temporal scope and geographical scope).

1) Goal: ensuring availability or ensuring accessibility
2) Resource scope: elements, configurations, or elements and configurations[4]
3) Temporal scope: 5, 25 or > 100 years
4) Geographical scope: country, continent or global scope

Combining all options for the four criteria results into 54 combinations. For those 54 combinations, a consistency- and relevance check was performed to evaluate which combinations appeared to be both logically consistent and relevant, in order to shorten the list of perspectives down to a workable number. This was both attempted during a physical meeting, and as a desktop exercise conducted by each member of the SUPRIM project team individually.

Even though the SUPRIM team members agreed to the very detailed definitions outlined in SI Table 1, and a structured procedure for narrowing down the list of 54 combinations, due to the complexity and multidimensionality of the topic of resource use, the reasoning of individual team members revealed differences in understandings of the definitions, and consequently, the outcome of narrowing down the combinations was far from a consensus. Therefore, it was decided to shift again to a top-down approach while drawing on the arguments and discussions from the bottom-up approach.

2.2.2.2. Taking a practicable shorter route. For practicality reasons, it was decided to narrow down the 54 combinations based on a majority vote. The team members were asked to decide on a maximum of two combinations of goal and scope definitions from the list of 54 combinations. This was simply decided as a straightforward approach to narrow down the list. Through this exercise, five of the combinations

[4] Configurations are naturally occurring abiotic materials like sand, clay, limestone, gypsum etc. (Van Oers et al., 2002)

Table 3
Results from the short route - selection from the list of 54 Type B combinations through majority vote, and suggested compromising actions.

Voters (number)	Goal: availability/ accessibility	Resource scope: elements, configurations or both	Geographical scope: Country, continent or global scale	Temporal scope:	Compromising action
4	accessibility	Elements	global	> 100 years	dissipation, competitive use
4	accessibility	Configurations	global	> 100 years	decrease of natural/anthropogenic stock through dissipation being greater than increase of stock through exploration
3	accessibility	elements	global	0–25 years	dissipation, competitive use
3	accessibility	configurations	global	0–25 years	Decrease of natural/ anthropogenic stock through dissipation being greater than increase of stock through exploration
1	accessibility	elements	global	0–5 years	dissipation and competitive use

remained (see Table 3). It was then suggested to reduce the list of combinations shown in Table 3 down from five to a more workable number of four, based on the previous inclusion or exclusion of the combinations by the individual team members.

The majority of the SUPRIM team members was in favour of the remaining four combinations (the first four combinations shown in Table 3). Consequently, it was decided to take forward those four combinations for further elaboration - from role, goal, scope, compromising actions towards problem definitions. In summary, all chosen perspective combinations share

- the Type B perspective, determined as the perspective type reflecting most stakeholders' interests/ concerns during the workshop. The Type B perspective is based on the use of resources by humans in the economy, and considers both primary and secondary production (e.g., mining and recycling).
- a concern which focusses on the accessibility (rather than availability) of resources (see SI Table 1 for a detailed clarification of the term accessibility as used in SUPRIM)
- a global scale as geographical scope

The focus on accessibility can be explained by the recognition of the observation that availability in itself is a necessary, but not a sufficient condition to enable human use of resources in the economy. Accessibility is an additional necessary condition. Furthermore, and more importantly, on a global scale, the availability of resources cannot be compromised if elements are considered, since elements cannot be destroyed, except through radioactive transformations, or losses into space, neither of which are considered here. Where configurations rather than elements are considered, the situation is different, since their availability can be compromised if they are destroyed through use.

The perspectives vary in terms of the types of resources they consider, i.e. elements, configurations or both. They consider mid- or long-term temporal scopes of 25 or 100 years, but no shorter temporal scopes.

2.2.3. Towards problem definitions: determining the compromising actions

For each of the five perspective combinations shown in Table 3, the team members were asked to (freely) determine the compromising action(s) they considered most relevant and important. The compromising actions can be considered precursors to more detailed problem definitions. For example, dissipation of resources is an action which could compromise the accessibility of elements under a global scope and a temporal scope exceeding 100 years. Table 3 shows a compilation of the answers. Compromising actions are the actions which lead to the problem. It can broadly be argued that the problem is then defined through the criteria outlined in Table 3, i.e. through the goal (accessibility or availability), scope, and the compromising action. For example, for the first combination listed in Table 3 the problem could be defined as ‘reduction in accessibility of elements through dissipation or competitive use on a global scale during a time period exceeding the next 100 years’. Since for each of the combinations, the role, goal and scope were already defined, the list of compromising actions turned out to be relatively short and thus manageable.

3. Discussion and outlook

The SUPRIM project was unusual in that it added an extra step prior to the orthodox development of an LCIA method: The development of a structured framework and the engagement of stakeholders in order to obtain a sound understanding of what is actually the problem that the indicator ought to reflect were introduced before the development of the indicator itself. The following discussion and outlook section reflects on the need for this step, i.e. on whether the procedure was worthwhile in terms of its insights for the research field of resource use in LCIA, and on whether a similar procedure might be beneficial in other topic areas relevant to LCIA.

3.1. Relevance of findings regarding the assessment of abiotic resource use (minerals and metals) in LCIA

A framework was developed with the intention to cover a number of important questions to enable the systematic elaboration of a number of perspectives on the use of abiotic resources, ultimately to provide more clarity on what is to be assessed in LCIA for the topic of abiotic resource use. If LCIA methods reflect the concerns of most stakeholders, they are more likely to be used by LCA practitioners, which again allows LCA as a method to contribute to the sustainable management of resources. The direct result from this exercise is first the definition of a perspective type, backed by a small but diverse and representative group of stakeholders of resource experts from industry, policy support, research and academia, who had discussed relevant issues within their networks beforehand, and are thus likely to reflect the thinking of their organizations. The Perspective Type was subsequently adopted by the 'Task Force Mineral Resources' as well. Second, it is the definition of four perspectives which were used as a foundation to develop methods on for the assessment of resource use in SUPRIM. Furthermore, the process outlined in this paper and the definition and selection of perspectives for SUPRIM can be used as an input for further work on this topic, i.e. the development of methods to assess the impacts of resource use. The work undertaken in SUPRIM has helped identify a number of important criteria regarding the perspective on resources which have often not been explicitly defined for LCIA methods on resource use (Fig. 3). The suggested criteria can help bring some transparency into the complex, multifaceted topic of resource use. Using a framework can also support the categorization of existing methods and thus the idea of a "toolbox", i.e. a guide to the large number of methods on resource use amongst which the users can choose the methods according to their needs. Furthermore, an effort has been made to define and distinguish the terms "availability" and "accessibility", which are central to the definition of the perspective on resources. If appropriately reflected by the chosen LCIA method, different perspectives on different multi-faceted issues should lead to different impact assessment results. For this reason, and for the sake of transparency, we consider it advisable to thoroughly define the perspective taken by each method.

3.2. Applicability of approach to other impact categories in LCIA

The observation of a mismatch between the intended perspective of an LCIA method and the perspective taken by the author of an LCA study that uses it has been given as a rationale for the development of new LCIA methods (Adibi et al., 2014; Schulze et al., 2017). This does not seem to be a phenomenon specific to metals and minerals though: For example, different perspectives on the use of water and their reflection in different LCIA approaches are discussed in the literature (Byrne et al., 2017; Le Roux et al., 2018) and water is also considered a resource. Therefore, beyond the immediate findings obtained from this consensus process, we reflect on other impact categories in LCIA which could also benefit from a structured approach to defining the perspectives to streamline and structure the further development of LCIA methods.

One impact category which may benefit from the use of a perspective-finding process is the topic of water use in LCIA. As with abiotic (and any other) resource use, the topic is complex and is being addressed from different perspectives. Perspectives on water use range from concerns over the availability of water relevant to the functioning of ecosystems in the respective watershed areas to concerns over competitive water use by humans for agricultural or other purposes (Boulay et al., 2018; Le Roux et al., 2018; Núñez et al., 2016). The topic also concerns human health impacts. As with abiotic resources, the maintenance or improvement of the quality of water can also be considered an alternative or additional goal to the management of its availability. Despite the apparent parallels between the management of metals and minerals versus the management of water resources, there are some differences which are likely to impact the choice of suitable modelling approaches. For example, water availability is typically considered a local (or regional) issue, whereas many metals are traded on a global market. Furthermore, with the use of abiotic resources, individual types of resources are evaluated against each other through characterization, since they can fulfill different purposes, depending on the stated perspective. Provided a suitable quality, water as such is in principle exchangeable.

Land use (change) is another impact category in LCIA where the application of a perspective-finding process might be beneficial to explain the underlying thinking and to inform further method development. A need for greater transparency of how land use (change) is addressed in LCIA has recently been highlighted in the literature (De Rosa, 2018). As with resource use, the topic can be considered from different perspectives, including the land's availability to produce biomass (Brandão and I Canals, 2013), the land's role in supporting biodiversity (Knudsen et al., 2017; Teixeira et al., 2016) and indirect impacts of land use change on global warming (e.g. through deforestation) (Schmidt et al., 2015). Other, more socioeconomic issues with land use may concern the availability of land for use by humans for agricultural or other purposes (De Rosa, 2018).

The assessment of biotic resource use has not played a large role in LCIA in the past (Sonderegger et al., 2017), but has received some more interest in recent years (see e.g. Crenna et al., 2018; Emanuelsson et al., 2014; Langlois et al., 2014; Bach et al., 2017). Biotic resources discussed in an LCIA context include fish stocks and a variety of other plants and animals which are hunted or harvested, but do not fall under the category of agricultural products (Sonderegger et al., 2017, citing Klinglmair et al., 2014). Some methods focus on biotic resource use only. Others, e.g. exergy-based methods, address both biotic and abiotic resources in parallel. Although recently some impact assessment methods have been developed for different types of biotic resources, the corresponding life cycle inventory data is often still missing, limiting the applicability of the methods (Crenna et al., 2018). As is the case with other resource related issues, the use of biotic resources can be approached from different perspectives. For example, Crenna et al. mention the role of the biotic resources in supporting ecosystem service functions and the role they play in socio-economic systems for human use. The differences in perspectives would consequently result in several different impact pathways, and thus, in several different methods. For this reason, and since the topic area is not too established in LCIA yet, it could benefit from a transparent and structured pre-indicator development process as conducted in the SUPRIM project for abiotic resources. Abiotic resource use, biotic resource use and water and land use (change) all fall under resource-related impact categories, which are complex, and have been busying the LCIA community for years (Alvarenga et al., 2016; Boulay et al., 2018; Dewulf et al., 2015; Guinée and Heijungs, 1995; Hauschild et al., 1998; Núñez et al., 2016; Schmidt et al., 2015; Sonderegger et al., 2017; Stewart and Weidema, 2005; van Oers et al., 2002). Some emission-related impact categories, such as global warming, eutrophication and acidification are more straightforward to assess than resource-related impacts since they are more established, with clear impact pathways and management goals. Those categories are thus less likely to profit from a consensus finding process prior to the development of an indicator. But emissions-related impacts may be very complex to assess as well, especially for endpoint models in LCIA (Bare et al., 2000) - for example when trying to model their effects on complex ecosystems. There, the complexity is not only due to challenges in physico-chemical fate modelling: Also, questions about the goal and scope as implemented in SUPRIM could help clarify the perspectives taken by the respective methods (Guinée et al., 2017; Tukker, 2002). Other new topics for impact categories in LCIA, in particular such complex and multifaceted topics as ecosystem services, and topic areas such as social LCA, which is currently less established than environmental LCA, could also benefit from a process similar to the SUPRIM consensus-finding process. The framework developed in SUPRIM could be considered a starting point for such perspective-finding processes which can be adjusted and developed further when applied in other topic areas. A method which can build upon a consensus process that was able to profit from the input from a carefully composed and diverse group of stakeholders can benefit from this process threefold: First, making an effort to obtain clarity regarding the perspective on a complex issue (such as resource use, water use etc.) *prior* to the development of a method is the basis for the development of an internally consistent method, since the authors themselves profit from the clarity. Second, the clarity obtained through the extensive discussions should enable an easy communication of the perspective which the method takes, making it quicker and easier for users to decide if the method fits their purpose. Third, a method which can rely on a consensus process backed by a diversity of stakeholders as done in SUPRIM is more likely to be supported in situations where a method recommendation is required, e.g. for use in EPD schemes, or in other private or public benchmarking situations.

Author contribution statement

The project team conceptualized the ideas presented in the manuscript. The first author wrote the first draft of the manuscript and revised the text as requested by the co-authors and reviewers. The co-authors contributed through the discussion of concepts and ideas, and by providing textual and verbal comments throughout the whole process.

Declaration of Competing Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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