SUPRIM

Sustainable management
of primary raw materials

SUstainable management of PRIMary raw materials through a better approach in Life Cycle Sustainability Assessment

How to better account for your primary raw materials in your LCA

EIT Raw Materials Project 2017 - 2019

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The state of the art of sustainability assessment for primary metal and mineral production

For its social licence to operate, the mining industry must address long-term development needs and opportunities in host communities. To address consumers' sustainability concerns, Life Cycle Assessment (LCA) tries to quantify the influence of an individual product system on the accessibility of minerals globally[1].

LCA has so far been unable to give a proper response to consumers on their contribution to reduced resource accessibility for next generations; firstly because resource accessibility is driven by economics and politics rather than an environmental mechanism, and secondly because there is a lack of suitable data to accurately describe the relevant processes.

This has raised two challenges, which SUPRIM has sought to address: provision of data for LCA and proper modelling within LCA.

The most commonly used LCA impact assessment indicator (Abiotic Depletion Potential) focuses on the availability of resources in the primary extraction medium (i.e. the earth's crust) (Guinée and Heijungs (1995); (van Oers et al. (2019)). Yet, accessibility of resources may be more relevant than availability, and it is important to distinguish the two.

Thus, at the beginning of SUPRIM, there was not a single consensual or standardised approach available to address impacts on natural resources with LCA. There was, therefore, a need to establish a new consensus.

Box: **Resource Availability versus Resource Accessibility**

Availability refers to the presence of a resource. I.e. the physical presence of a resource independent of its potential for human use.

Accessibility refers to the possibility of making use of the availability of a resource. I.e. the amount of resource present that can be accessed for use in human applications.

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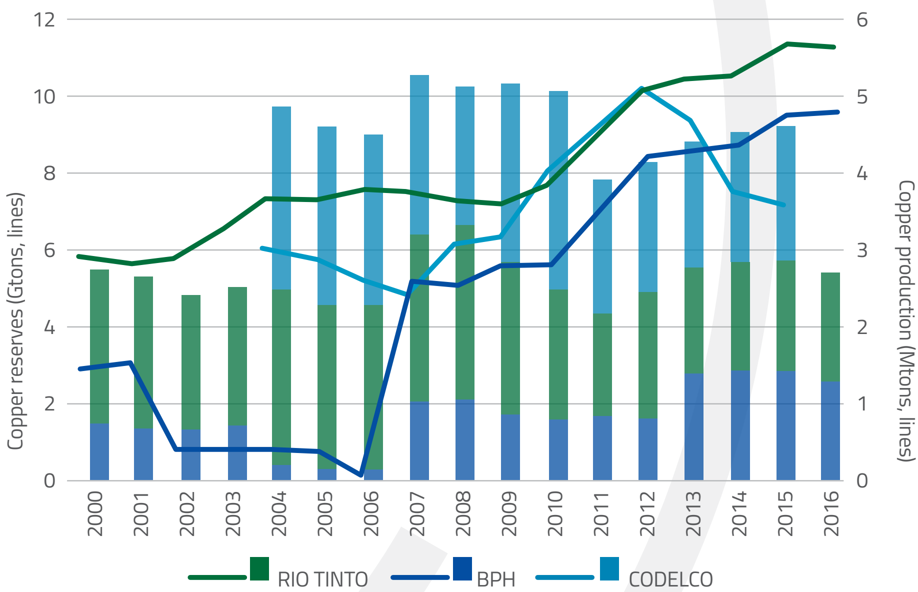
[1] *Another EIT Raw Materials funded project, CERA, has proposed that four different assessment tools are required to address the different assurance needs of businesses depending on their position in the value chain (https://eitrawmaterials.eu/project/cera/).*

Meanwhile, release of data for LCA is an issue for the industry as it has led to misinterpretation and potential confidentiality issues. This, combined with little relevance for host communities, affects the primary producers' potential business case for making such data available.

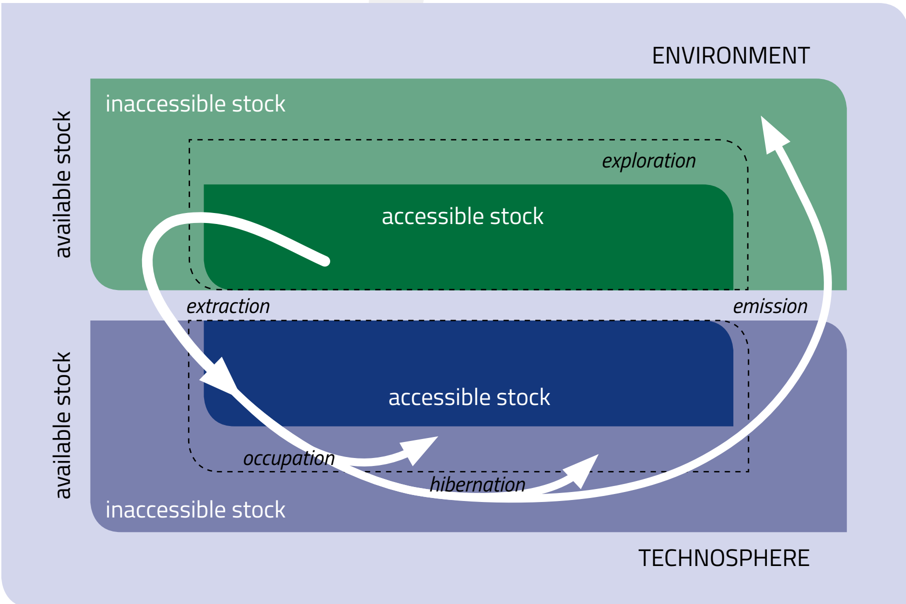
Exploration moves metal and mineral occurrences into the economy in that identified deposits are already bought and sold as assets in situ. Whilst metal production has increased over time, global reserves have also increased. More variation is visible at the enterprise scale than at the long-trending global scale. E.g., copper production from the five largest copper producing companies has varied individually, while the general trend has been a significant increase in their combined copper reserves. Metal reserves (as opposed to the Earth's total endowment) are dynamic and should not be regarded as fixed stocks.

Figure 1 from the full report: Enterprise-scale copper production (Mt) and reserve base (Gt) between 2000 and 2016. Data from BHP, Rio Tinto and Codelco.



A consistent LCA model of impacts on accessibility of resources should reflect this reality and, at the same time, its problem definition, impact assessment method and data inventory should be based on the same system model.

Figure 2: An example of a system model as basis for LCA model development (Oers et al., 2019 submitted).

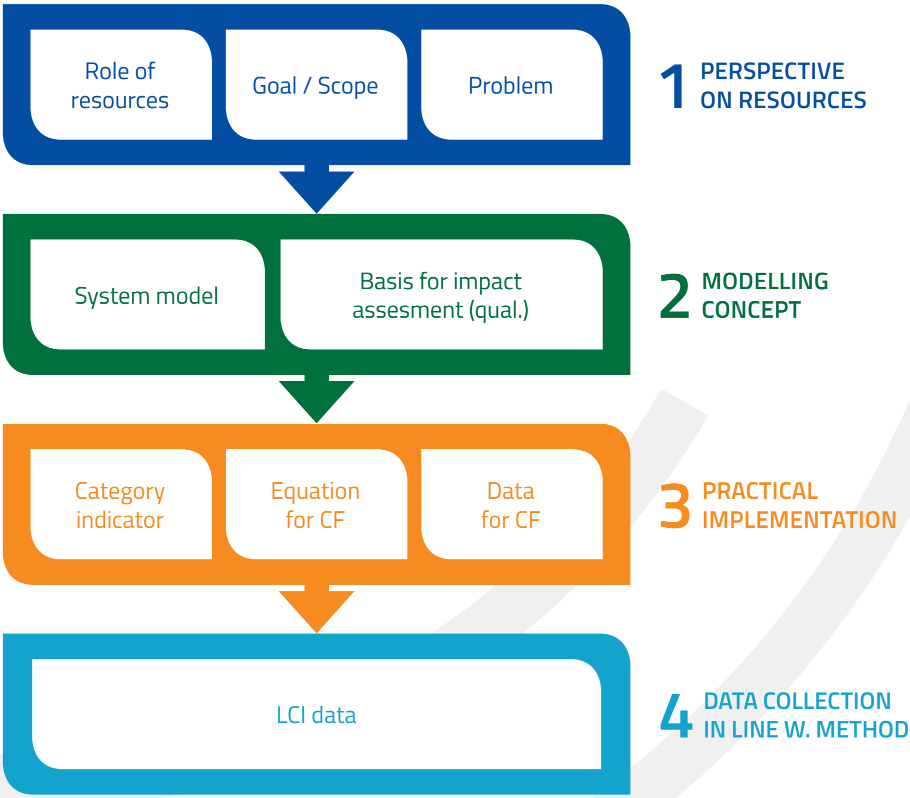


SUPRIM stakeholders agreed that the perspective of most common interest was accessibility of both primary and secondary resources for use by humans in the economy. However, previous method developers have had different views on the key constraints to accessibility of resources, i.e. the problem to address. Additionally, a SUPRIM review showed that not all the existing methods were even based on consistent reference to a single system model.

Agreed problem definition and method

The focus of SUPRIM was on defining problem definitions and impact assessment models for Life Cycle Impact Assessment. The approach taken was to move to a strategic discussion clarifying the issue in a systematic way, understanding industry, policy and academic views on the role(s) of abiotic resources that need protecting.

Figure 3: The framework developed by SUPRIM to answer LCIA modelling questions in a structured manner.



1 – PERSPECTIVE ON RESOURCES

At the top-left of Figure 3, answering the question of why resource use is of concern explained what should be protected and why, defining the 'role' of resources as the way the resources are valued.

The goal with regards to the protection of resources also needed to be defined. It could be defined in relation to scope, defined as a certain time, a certain geography, and certain types of resource (e.g. elements or materials).

The problem to be defined is what prevents the defined goal from being achieved. A range of roles and goals is possible, so the perceived problem with resource use can vary accordingly.

SUPRIM identified through a multi-stakeholder process that both **new and used resources are valued for their usefulness to humans in the economy**. Different resource management goals are set depending on one's position in the supply chain, but most are concerned about **accessibility of resources within different timeframes**. This reflects a clear focus on **ensuring supply can meet demand** and how such a balance should be achieved, i.e. by acting at the demand-side or the supply-side or both.

SUPRIM focused on the problem defined **as the potential decrease of accessibility of primary resources (in Nature) and/or secondary resources (in the Economy) on a global level on the Short Term (25 years) or Long Term (500 years)**.

Practitioner stakeholder workshop on an enhanced LCA methodology for Resources, Berlin, May 2019

2 – MODELLING CONCEPT

At the second level of Figure 3, answering the question of which resource flows are relevant to the problem explained how impacts on accessibility occur, defining the system model including the flows to be assessed by the LCIA method.

The basis for impact assessment is the criterion according to which the use of one resource is evaluated against the use of another, which also must be in accordance with the defined problem and system model (see Figure 2).

Due to **exploration**, innovation and changed demand, the known accessible stock in Nature may increase or decrease from one moment to the next. Within the economy, **hibernation** (e.g., in abandoned products, landfills and tailings) and **occupation** (in use in an existing application) make resources in the Economy temporarily inaccessible from one moment to the next. Extraction of a resource causes a decrease of the known accessible stock in Nature and an increase of the stock in the Economy. An **emission** will lead to a decrease of the resource stock in the Economy.

In the SUPRIM system model (Figure 2), emissions are considered an addition to the inaccessible stock in Nature. That is, SUPRIM assumes that an emitted resource will no longer be accessible for human use over the considered time horizon.

SUPRIM determined that **inaccessibility** of a resource is a function of the global **accessible stock (in Nature and the Economy) and changes to it**. In turn, changes to the global accessible stock occur as a function of **exploration, occupation in use, environmental dissipation**, and **technosphere hibernation** (synthesis and destruction also play a role, but not for resources defined as individual natural elements).

3 – PRACTICAL IMPLEMENTATION

At the third level of Figure 3, answering the question of how to express the modelling concept mathematically, explained how impact assessment results could be calculated, defining the LCA Characterisation Factors and how to apply them to the relevant resource flows.

SUPRIM developed three equations to quantify the impact of changes to global accessible resource stocks: one for **Environmental Dissipation**; one for **Technosphere Hibernation**; and one for **Occupation in Use**. (**Exploration** is also accounted for in the background balance of stocks).

$$EDP_{(T,i)} = \frac{E_{(T,i)} / R^2_{(i,tot,t+T)}}{E_{(T,ref)} / R^2_{(ref,tot,t+T)}} \qquad THP_{(T,i)} = \frac{H_{(T,i)} / R^2_{(i,tot,t+T)}}{H_{(T,ref)} / R^2_{(ref,tot,t+T)}} \qquad OUP_{(T,i)} = \frac{O_{(T,i)} / R^2_{(i,tot,t+T)}}{O_{(T,ref)} / R^2_{(ref,tot,t+T)}}$$

The Environmental Dissipation Potential ***(EDP)*** was defined as the cumulative global **emissions** of resource i over time horizon T divided by the total global accessible **stock** of resource i in Nature and the Economy squared (relative to the same ratio for a reference resource).

The Technosphere Hibernation Potential ***(THP)*** was defined as the cumulative global amount of resource i **hibernating** in the technosphere over time horizon T, divided by the total global accessible **stock** of resource i in Nature and the Economy squared (relative to the same ratio for a reference resource).

The Occupation in Use Potential ***(OUP)*** was defined as the cumulative global amount of resource i **occupied** in use over time horizon T, divided by the total global accessible **stock** of resource i in Nature and the Economy squared (relative to the same ratio for a reference resource).

Given the uncertainties of future developments, the total global accessible stock of resources in Nature and the Economy is unknown and will remain unknown (until the end of times). For a relative assessment of the contribution of the use of different resources to reduced accessibility over the long term, the **Crustal Content** is an acceptable proxy. The total global accessible stock of resources that is shifted into the Economy over time horizon T, can be thought of as the result of the **cumulative extractions** of elements from the environment minus the **cumulative**

emissions, which is relevant for shorter term considerations of hibernation and occupation in use. Finally, over the very long term, the cumulative global emissions of resources extracted from Nature today can be thought of as being equal to the total amount of resources extracted from Nature today. That being the case, the Environmental Dissipation over the long term can be reduced to:

$ED_{(T,i)} = \sum_i ADP_{(i,t)} \times$ *the amount of resource i emitted by the product system*

Thus, **the equation for EDP mathematically resembles the old ADP (Guinée and Heijungs (1995); van Oers et al. (2019)), except that it is not applied to the flow of resources extracted from the environment, but to the flow of resources emitted from the economy**.

In LCA, Characterisation Factors are only multiplied by flows that cross the boundary between the environment and the economy. Of the three SUPRIM proposals, **only the Environmental Dissipation Potential is consistent with LCA practice**, using quantified emissions as input to the LCA. The Technosphere Hibernation Potential and Occupation in Use Potential use resource flows that occur between processes within the economy (the technosphere).

To begin with, the actual ED, TH and OU scores might be challenging to calculate. Each of the LCA Characterisation Factors should be multiplied by the relevant flows from the Life Cycle Inventory: emissions to the environment, flows in & out of hibernation within the economy, and flows in & out of occupation in use.

In general, LCI databases of **emissions** from unit processes are incomplete. In most cases, what is reported as going into a unit process seldom tallies with what must come out. Additionally, LCI databases do not list emissions of elements, but of chemical substances. SUPRIM proposes to derive LCA Characterization Factors for element emissions based on the standard chemical formulae of the reported substances emitted.

Although existing LCI databases already include some flows to **hibernation** and **use**, present LCA software packages do not generally aggregate them in a way that can be attributed to the product or service being assessed. To calculate TH and OU, the necessary resource flows can be taken from process to process matrices, taking care to avoid double-counting of impacts. In LCA language, this means making a clear distinction between "parts of the cause-effect chain belonging to the inventory and those belonging to the impact assessment". However, as noted above, this would represent a significant departure from LCA practice.

4 – CASE STUDIES AT MINING COMPANIES BOLIDEN AND COBRE LAS CRUCES

To test data collection methods at mining companies, the Functional Unit defined for the case studies was "To produce 1 kg of copper cathode". Copper cathodes are the sheets of 99,99% copper that are used to make everyday products. At the Cobre Las Cruces mine, a hydrometallurgical process is used and the process from mining to cathode production occurs on site. At the Aitik mine, a concentrate is sent for pyrometallurgical processing and the smelting processes are located 410 km away. The smelter there processes scrap and ores from several mines to produce different products. Allocation procedures were therefore required to identify the Aitik mine's share of the Rönnskär smelter cathode production.

Mining. The first steps in the mining process are drilling and blasting. To access the ore, boring machinery is used to drill holes into the rock, and explosives are inserted into the holes to blast and break the rock. At Aitik, the blasted rock is loaded into trucks by mechanical loaders for transport to crushing stations. At Las Cruces, the ore is transported to an ore storage area, where different ore grades are mixed to obtain a feed with stable copper concentration.

Comminution. At Las Cruces, crushing is carried out in three stages including a jaw crusher and two conical crushers and two screens separate the resulting particle sizes. Aitik ore is broken down at three crushing stations located at different levels within the mine. At both mines, the ore is then finely ground to produce an aqueous pulp. At Las Cruces, it is thickened before it enters a leaching process. At Aitik, the pulp enters a series of flotation tanks. Air, flotation agents and agitators cause the valuable minerals to adhere to air bubbles, which are collected from the surface of the tanks.

Metallurgy. At the Rönnskär smelter, copper from the Aitik concentrate is roasted and/or smelted, converted to blister copper, cast into anodes and electrolytically refined into 99,99% pure cathode. At Las Cruces, copper from a thickened concentrate pulp is leached, extracted with an organic solvent, and electrolytically refined into 99,99% pure cathode.

To get more precise information of the resource flows related to copper from Aitik, Rönnskär smelter staff had to divide the flows into three subsystems: (1) Primary-Copper-related flows; (2) Non-Primary-Copper-related flows; and (3) Generic flows. This was done based on knowledge from Rönnskar staff. It allowed more differentiation and clarity about the relation between certain input/output flows to each process/product in the overall smelter system.

Even after this, it was necessary to determine the Aitik mine's shares of the Rönnskar smelter system's flows of concentrates and resulting copper cathode because the smelter also produces other products. SUPRIM followed established industry practice for allocation of copper smelting system flows according to economic importance. The calculations suggested that 29% of the flows from the Primary-Copper-related flows related to copper from the Aitik mine, none of the flows from Non-Primary-Copper-related flows were associated with Aitik, and 17.5% of the flows from the common processes (Generic flows) related to copper from Aitik. The remaining resource flows within the Rönnskär smelter were assumed to be a result of production of other products from other raw materials (e.g., scrap and concentrates from other mines).

Open pit, Cobre las Cruces

Case Study results from Cobre las Cruces without impacts on resources

Leaving impacts on resources aside to begin with, the case study results at Las Cruces suggested that most of the environmental impacts invoked "to produce 1 kg of copper cathode" were due to **use of energy and materials**, rather than being due to transport, emissions or generation of waste. The processes that appeared to contribute most to these impacts were **upstream supplier processes** used to manufacture diesel, electricity, explosives and liquid oxygen. At Las Cruces, these materials are mostly used for **blasting** the ore (explosives), **transporting** the ore out of the mine (diesel), **leaching** the ore (oxygen) and electrolytic **refining** of the pregnant leach solution (electricity).

To summarise, the main potential hotspots identified at Las Cruces were

- "Climate Change", "Ionising Radiation", "Acidification" and "Ozone Depletion" from the generation of **electricity purchased** for use in the copper cathode manufacturing process.
- "Freshwater Eutrophication" from the manufacture of **liquid oxygen purchased** for use in the leaching process.
- "Terrestrial Eutrophication", "Photochemical Ozone Formation" and "Marine Eutrophication" from manufacturing of **explosives purchased** for blasting, and
- Several environmental impacts from production of **diesel purchased** to fuel equipment in the mine

Hydrometallurgical plant, Cobre las Cruces

Case Study results from Aitik without impacts on resources

Leaving impacts on resources aside to begin with, the case study results at Aitik suggested that most of the environmental impacts invoked "to produce 1 kg of copper cathode" were due to **use of energy and materials**, rather than being due to transport, emissions or generation of waste. The processes that appeared to contribute most to these impacts were **upstream supplier processes** used to manufacture diesel and explosives. At Aitik, these materials are mostly used for **blasting** the ore (explosives) and **transporting** the ore out of the mine (diesel).

To summarise, the main potential hotspots identified at Aitik were

- "Climate Change" and "Marine Eutrophication" from manufacturing of **explosives purchased** for blasting and **diesel purchased** to fuel equipment in the mine
- "Climate Change" directly from the use of diesel to **transport** material out of the mine
- "Ionising Radiation" and "Ozone Depletion" from the generation of **electricity purchased** for use in grinding the ore at the mine, and
- "Acidification" and "Photochemical Ozone Formation" from the **smelting** of Aitik concentrate at Rönnskär

Aitik Plant Overview, Photo: Lars deWall

Case studies of the new SUPRIM method to assess impacts on resources

Testing of the new SUPRIM Environmental Dissipation impact category (long-term) required application of the method to the case study data from Aitik/Rönnskär and Las Cruces. To compare the results to the current state of the art, the ADP (Guinée and Heijungs (1995); Oers et al. (2019)) was also calculated.

The total ***Abiotic Depletion*** impact score obtained to produce 1kg of copper cathode from Aitik ore was calculated. **Most of the impact score was generated from the extraction of copper ore** in the mine (98%), with minor contributions from extraction of other elements like platinum and palladium. Similar results were obtained for the Las Cruces case study, of which copper contributed nearly 100% of the impact score.

In contrast to the Abiotic Depletion scores, the ***Environmental Dissipation*** impact scores of the case studies were generated from **dissipation of several elements within the processes** to produce 1kg of copper cathode. At Las Cruces, the total ED impact of the system was calculated. The highest relative contributions appeared to come from dissipative losses of platinum, and cadmium. These losses were traced back to possible **upstream processes to produce purchased explosives** (Pt) and **purchased sulfuric acid** (Cd). The highest relative ***ED*** contributions at Aitik appeared to come from dissipative losses of platinum, and antimony (more than 80% of the total). Such losses were traced back to possible upstream processes to produce purchased explosives (Pt) and potential **brake wear emissions** associated with use of mobile equipment within the mine (Sb).

One obstacle found to complete application of the SUPRIM method is available data of some resource emissions reported as substance groups rather than as single substances (e.g., aldehydes). Some substances had to be left out due to the lack of a specific chemical composition (e.g., acidity) in the available data. In general, it can also be expected that the generic databases used for emissions from upstream processes were probably incomplete. In many cases, what is reported in such commercially available databases as going into those unit process seldom tallies with what must come out.

From the point of view of a primary raw materials producer, **these preliminary results are encouraging**. Whereas, the results of current state of the art LCA, using the Abiotic Depletion Potential characterise the whole basis of the supply chain

Aitik open pit mine. Photo: Lars deWall

as an environmental impact (extraction of copper), the SUPRIM Environmental Dissipation Potential results provide more useful information, because they raise questions about ways to improve materials stewardship and reduce environmental impacts within the supply chain (either in procurement of supplies for the mine, or in the mining and metallurgical processes themselves). **Whereas *ADP* effectively measures production in the mine, *EDP* measures loss of resource value from all processes within the mine and onwards downstream.** This of course reflects the difference between the problem addressed by ADP and the problem defined by stakeholders during the SUPRIM project and addressed by EDP.

The results of the SUPRIM case studies appear to confirm that the SUPRIM Environmental Dissipation Potential indicator can be used to inform about impacts to the accessibility of elements on a global level over the long term in a way that is meaningful for all actors along value chains and consistent with the concept of maintaining the value of resources within the economy.

Value from the outcomes of SUPRIM

Resource accessibility for humans in the future is a complex concept and therefore needs to be adequately understood and reflected. The general equations for characterisation Life Cycle Impact Assessment models developed by SUPRIM represent a new state-of-art and are the most reliable of their kind thanks to the unique mix of expertise existing within the project consortium.

The results turn out to be consistent with previous agreement across disciplines (geologists, mining experts, and environmental scientists) that dissipative outflows from studied systems—rather than inflows to them—are the concern to address in order to maximise continued accessibility of raw-materials (Drielsma et al. (2016)). The equations give recognition to the fact that resources are not always consumed or dissipated, but often remain available as an anthropogenic source for secondary production (recycling). Temporary use or hibernation of resources within the economy can be an issue for accessibility - mostly in the short term, not in the long term.

The proposed SUPRIM method also responds to the European Commission's call to develop a life-cycle based impact assessment method for resource use based on dissipation concepts for use in its Product Environment Footprint and Organisation

Environment Footprint methodologies. The project has resulted in preparation of five separate publications for inclusion in peer-reviewed scientific journals, which can be referenced in future for this purpose.

Regarding the collection of data from mining operations, SUPRIM can provide insights for academics and the EIT Raw Materials into how to approach mining companies and mining sites (local management), e.g., which social, cultural and other soft skills are needed to be effective; and how to deal with likely challenges and roadblocks.

Primary raw materials producers would welcome a cost-efficient solution to retrieve environmental data from their activities for environmental assessment of their products through LCA, anticipating a growing interest from downstream users and final users and consumers. SUPRIM has identified that a still missing piece of such a solution, is a viable business case for providing the data necessary to perform LCA (Alvarenga et al. (2019)), but that the SUPRIM method of LCA impact assessment can make better use of the data to inform companies about ways they can improve materials stewardship and reduce their impacts on the long term accessibility of abiotic resources.

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