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A change of paradigm on mineral resources flows in LCA: necessary, and feasible

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1. Introduction

Mineral resources are essential to make modern societies thrive while meeting Sustainable Development Goals. The assessment of impacts associated with mineral resource use has long been debated among life cycle impact assessment (LCIA) method developers and LCA practitioners. The Abiotic Depletion Potential (ADP) method is recommended i) by the task force mineral resources of the United Nations Environment Programme (UNEP) Life Cycle Initiative (GLAM2 context), and ii) as part of the Product Environmental Footprint of the European Commission. In LCA, “mineral resources, extracted from ground” are the only type of mineral resources *elementary flows* reported in Life Cycle Inventories (LCIs). The ADP method assumes that the extraction of these mineral resources from the ecosphere (as accounted for in LCIs) reduces the natural (geological) stock. ADP characterization factors have been, and are, extensively implemented in daily LCA practice, through the use of adapted LCI databases and LCA software. However several methods have been developed in the recent years to address reduction of resource accessibility and resource dissipation in LCA; including the EDP, ADR/LPST, ARP, JRC-LCI, CTI-LCIA and EVDP methods.

This study aims at i) analyzing the fundamentals of these methods, including key underlying choices and assumptions, and operationalization; ii) discussing the representation of mineral resources flows in current LCI practice, and associated limitations in view of these recent developments; and iii) paving the way for a change of paradigm on mineral resources flows in LCI.

2. Materials and Methods

This study first intends to highlight why a change of paradigm on mineral resources flows in LCA is necessary. To do so, it builds on a recent article [1] analysing the EDP, ADR/LPST, ARP, and JRC-LCI methods, discussing assumptions and modelling choices on which they build, and their operationalization in the LCA context. In this study, the analysis is further extended to include the CTI-LCIA and EVDP methods.

Secondly, this study intends to demonstrate that this change of paradigm may be feasible in practice. It first analyses the terminology associated with, and operational representation of, “material flows” in LCI modelling. It moreover discusses the implementation of material balancing in process engineering and Life Cycle Thinking. Building on lessons learnt from this analysis, it develops a stepwise approach to derive balanced LCI datasets and databases.

This discussion is supported by a case study, considering the primary production of a battery raw material, using ecoinvent 3.10 datasets. The developed framework is showcased with step by step implementation, finally discussing the influence on resources (accessibility and dissipation-based) and environmental impact assessment.

3. Results and Discussion

3.1. Changing paradigm on mineral resources flows in LCA: necessary

This study highlights the two pivotal aspects that make necessary a change of paradigm on mineral resources in LCA.

Several methods (ADR/LPST, EDP, ARP) have been tailored to be implemented using current standard LCI data formats (*Table 1*). These methods are readily operational with current LCI databases, but in the meantime build on some disputable assumptions. Other methods instead pledge for new LCIs to be developed (JRC-LCI method), or require the development of new LCIs (EVDP, CTI-LCIA) for any potential wide implementation. This second set of methods calls for a deep change of paradigm on modelling mineral

resources in LCIs, no longer considering only primary mineral resources extracted from ground, but also mineral resources flows within the technosphere or from the technosphere to the ecosphere.

Method	Concept captured	Practical implementation	Temporal scope	LCI resource flows to which CFs apply
ARP	Dissipation	Classification of dissipative flows in LCI	Very long term to infinite	NA
JRC-LCI	Dissipation	Addition and classification of dissipative flows in LCI	Short-term	NA
ADP ultimate reserves	Depletion	CFs multiplied by inventory flows	Very long term to infinite	Resources from ground
EDP	Dissipation	CFs multiplied by inventory flows	Very long term to infinite	Emissions to environment
ADR and LPST	Dissipation (midpoint)	CFs multiplied by inventory flows	Short-term and long-term	Resources from ground
	Value Loss (endpoint)			

Table 1: Key characteristics of five methods to address mineral resource use in LCA [1]

Secondly, rethinking mineral resources flows in LCIs is necessary to support material-balanced LCIs. In particular the JRC-LCI method builds on a so-called “resource flow analysis” at the unit process level. It ensures balanced quantification of resource flows at the unit process level, to further quantify all the output dissipative flows of resources. Balancing mineral resources flows at the unit process level enables improved LCI modelling, contributing to more consistent and complete accounting of intermediate exchanges, emissions and resources flows.

3.2. Changing paradigm on mineral resources flows in LCA: feasible

This study further develops a stepwise approach to make this change of paradigm applicable in LCA practice. This approach integrates material accounting and balancing principles in LCI results, enabling to derive balanced LCI datasets and databases. It builds on a new nomenclature of mineral resource flows, not only extracted from ground but also exchanged within technosphere, and from technosphere to ecosphere.

This framework is showcased with step by step implementation to the case of the production of a battery raw material. The influence on toxicity- and resources-related impact categories is discussed, particularly highlighting the benefits gained from this framework towards sounder support to decision-making.

4. Conclusions

This study supports a change of paradigm on the accounting of mineral resources flows in LCI databases. This change of paradigm is necessary for LCA to effectively support resource-efficient, and more generally environmentally sound, decision-making. This is particularly crucial for LCA to be supportive when applied to sectors and products largely relying on mineral resources. The framework presented and showcased in this study supports the deployment of this change of paradigm in LCA practice.

5. References

[1] Beylot, A., Dewulf, J., Greffe, T. *et al.* Mineral resources depletion, dissipation and accessibility in LCA: a critical analysis. *Int J Life Cycle Assess* 29, 890–908 (2024). <https://doi.org/10.1007/s11367-023-02278-3>

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