Towards the integration of mineral resource dissipation in life cycle inventories: insights from ecoinvent-based case studies

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1. Introduction

One of the most widely applied approaches to account for the impacts associated with mineral and metal resource use in the Life Cycle Impact Assessment (LCIA) step relies on the concept of “depletion”: the extraction of a resource from the Earth’s crust is considered to contribute to the reduction of this resource’s geological stock (and subsequently to its depletion). However, debates have recently risen within the LCA community to question this depletion concept, as a resource is not necessarily exhausted once extracted but rather remains in the technosphere therefore contributing to the formation of an anthropogenic stock. This has led to the emergence of the “resource dissipation” concept, considering the dissipation of a resource once it is rendered inaccessible to future users [1]. While the depletion concept implies associating the impacts of resource use with the mining step of a product/system life cycle, considering the dissipation concept implies accounting for resource losses along the whole product/system life cycle, including the use and end-of-life phases. The operationalisation of the latter concept in LCA requires two conditions: i) information about dissipative flows in the Life Cycle Inventories (LCI), and ii) impact characterization models accounting for the impacts associated to resource dissipation [2]. To account for the dissipative flows of mineral resources along product life cycles, a new approach was developed by the Joint Research Center (JRC) of the European Commission, with an example of application to existing LCI datasets considering the cradle-to-gate production of primary copper [1]. In this context, this study aims at further extending the application of the JRC approach to currently existing LCI datasets drawn from the ecoinvent v3.7 database considering, on the one hand, different cradle-to-gate metal production systems, and on the other hand, the cradle-to-grave lithium-ion battery system. In particular, this study aims at i) assessing the dissipative flows of mineral resources along these different systems, and ii) using these results as a basis to provide insights as to the generalisation of the approach and its integration in the current and future LCI databases.

2. Materials and methods

2.1. Description of the JRC approach

The approach suggested by the JRC consists in accounting for the dissipative mineral resource flows at the level of each unit process of the life cycle [1]. The implementation of this approach follows two steps:

1) A resource flow analysis (RFA), which consists in tracing each mineral resource input and output in each unit process. RFA is key for several purposes. In particular, among the output flows of substances, only the ones that are identified to be resources entering the activities under study can be classified as dissipative flows of resources. Accordingly, it first requires to identify the mineral resources as extracted from ground or embodied in products-in-use in each unit process. Moreover, the use of the mass balance equation in the RFA enables to ensure the consistent mass balance of resources along the system under study.

2) An identification of the dissipative flows, based on the resource flow analysis. The dissipation concept may be relatively sensitive to the temporal perspective considered, as the accessibility to a resource may vary depending on the time horizon (e.g. reprocessing of mining wastes may be assumed in a long-term perspective). In this study, a short-term perspective over 25 years is considered. This implies that three main dissipation compartments can be distinguished: environment; final waste disposal facilities; products-in-use in which the resource provides a low-functionality (e.g. copper in slags used in construction works).

2.2. Ecoinvent case studies

Different case studies based on ecoinvent v3.7 inventories are considered in this study:

- The cradle-to-gate primary production of 9 metals (including base, rare and precious metals) and 1 non-metallic mineral resource: lithium (Li), manganese (Mn), copper (Cu), aluminium (Al), cobalt (Co), nickel (Ni), rare earths (RE), platinum group metals (PGMs), silicon metal (Si) and graphite. Regarding these materials, the system boundaries cover the extraction of the resource from the environment (mining), the ore processing on the mine site (concentration) and the metal production through metallurgical processes.

- The cradle-to-grave production of a lithium manganese oxide (LMO) battery for electric vehicles as modeled in the ecoinvent v3.7 database. In particular, this study focuses on the two main components of the battery, i.e. the cathode and the anode, considering their active materials, respectively lithium manganese oxide and graphite, and their collector foils, respectively aluminium and copper. In this case, the system boundaries cover the cradle-to-gate productions of each material, the battery manufacture encompassing the manufacture of both cathode and anode as well as the manufacture of the Li-ion cells, the use phase in the electric vehicle and finally the end-of-life disposal including both the potential functional recovery of resources from the recycling of the battery and other disposal routes.

3. Results and discussion: focus on the cradle-to-gate production of lithium

Overall, the cradle-to-gate production of 1 kg lithium carbonate (Li_2CO_3) generates 0.48 kg of direct dissipative mineral resource flows along its process chain. Lithium carbonate production from concentrated brine accounts for 87.6% of the dissipative flows in a mass perspective, whereas other processes in the cradle-to-gate chain (e.g. spodumene production) have more limited contributions (Figure 1). Sodium accounts for the largest share of the dissipated resources (78%), followed by lithium (13%); while final waste disposal facilities represent the main dissipation compartment (90%). In particular, regarding the dissipative flows of lithium, 78% of the flows occur in final waste disposal facilities, respectively dissipated in the production of Li_2CO_3 from brine (57%) and spodumene (21%).

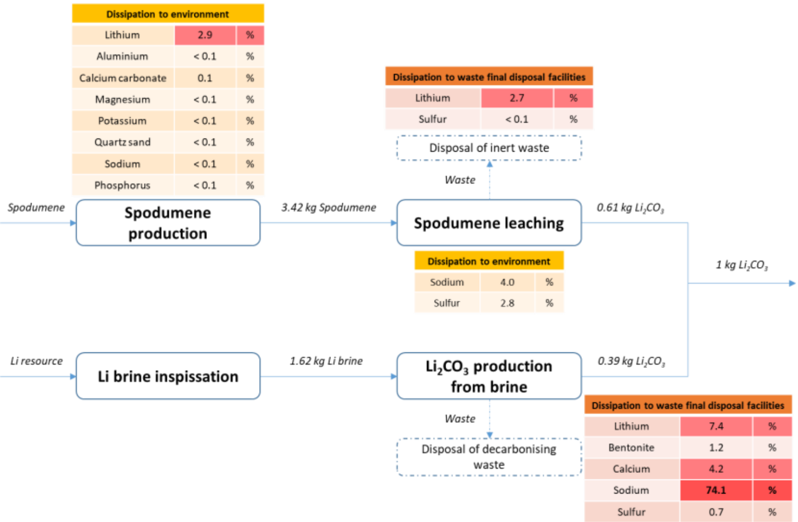

Figure 1: Dissipative flows along the cradle-to-gate production of 1 kg lithium carbonate

Moreover, building on the analysis of the results from the case studies, this study discusses the potentialities for the systematic replication of such an accounting of dissipative resource flows at a large scale in standard LCI databases.

4. Conclusions

The implementation of the JRC approach to the ecoinvent database appears as a promising step towards the full integration of the resource dissipation concept in LCI. However, two main challenges are yet to be overcome to secure the assessment of resource dissipation through the database: i) improve the quality of datasets showing some inconsistencies; ii) automate the application of this approach to an extensive number of LCI datasets, building on the knowledge obtained from the application to the metals sector.

5. References

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