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Perspective

A necessary step forward for proper non-energetic abiotic resource use consideration in life cycle assessment: The functional dissipation approach using dynamic material flow analysis data

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The impact of non-energetic abiotic resource use in life cycle assessment (LCA) has been receiving much attention in the last decades, and even more so since the resource efficiency and circular economy have become prominent subjects of discussion in public and private sectors all around the world. As LCA has proven to be the most solid holistic tool to integrate environmental impacts in sustainability assessments of product systems, it should be able to integrate current concerns about non-energetic abiotic resource use into its methodology and therefore provide exploitable results for every LCA user. However, to this day no consensus has been reached on which approach for characterizing impacts due to the use of these resources should be used (Drielsma et al., 2016; Sonderegger et al., 2017). This seems to be attributable to the fact that no method is recognized as both solid on the methodological level while answering at the same time the true concerns for abiotic natural resource uses in LCA: the need to retain and therefore maximize their functional value in the technosphere after their extraction in order to fulfill the needs of current and future generations, while minimizing the losses to the ecosphere.

Indeed, abiotic resources are not always consumed or dissipated after their extraction, but may remain available as anthropogenic source through recycling for many life cycles (Drielsma et al., 2016). Accordingly, the safeguard subject for "mineral resources" has been defined by the UN Environment's Life Cycle Initiative task force as "the potential to make use of the value that mineral resources, as embedded in a natural or anthropogenic stock, can hold for humans in the technosphere" (Berger et al., 2018). This recent task force document, in line with Drielsma et al. (2016), also highlights that dissipation is a new potential way to be further explored to consider non-energetic abiotic resource use in LCA.

Damages to the three Areas of Protection (AoPs) Natural Resources, Human Health and Natural Environment occur when abiotic resources are dissipated in a way that makes them unavailable for future use (i.e. as dissipated content in the environment, or latent in the technosphere, or loss of quality). Hence, the challenge ahead is to use a dissipation approach for non-energetic abiotic resources, including their changes in quality, to improve the consideration of these resources in LCA studies.

This is an impossible task using current life cycle inventories (LCIs), since abiotic resource flows that are extracted from and emitted to the environment are not considered in a consistent way. Indeed, process data in widespread databases only include values for extraction and emissions to the different environmental compartments, with inconsistent in-out mass balance, and contain aggregated data following allocation procedures in-between product systems as well as supporting activities, which make it impossible to isolate and track all of the dissipated resources linked to a product system. Moreover, as indicated in the seminal report by the European Commission's Joint Research Centre on dissipation in LCA, resource outflows inside technosphere should be assessed even though they do not cross the environment-technosphere boundaries (Zampori and Sala, 2017) (Fig. 1).

Overall, this means we need to address the dissipation of non-energetic abiotic resources in two ways: by improving the life cycle inventories and by developing new characterization factors (CFs) for the AoP of Natural Resources. As dynamic material flow analysis (dMFA) allows to monitor flows within and outflows of a system within a dynamic timeframe, it enables the calculation of dissipation curves inside different compartments over time for a material or substance. Hence, we propose two options allowing the transition towards the application in LCA of a functional dissipation approach based on dMFA and a specific conceptual LCIA framework:

1 The implementation of dMFA dissipation ratios in LCIs to include dissipation into the ecosphere and/ or temporary stocking inside the technosphere and the conversion of these flows in an environmental impact on the AoPs Natural Resources, Human Health and Natural

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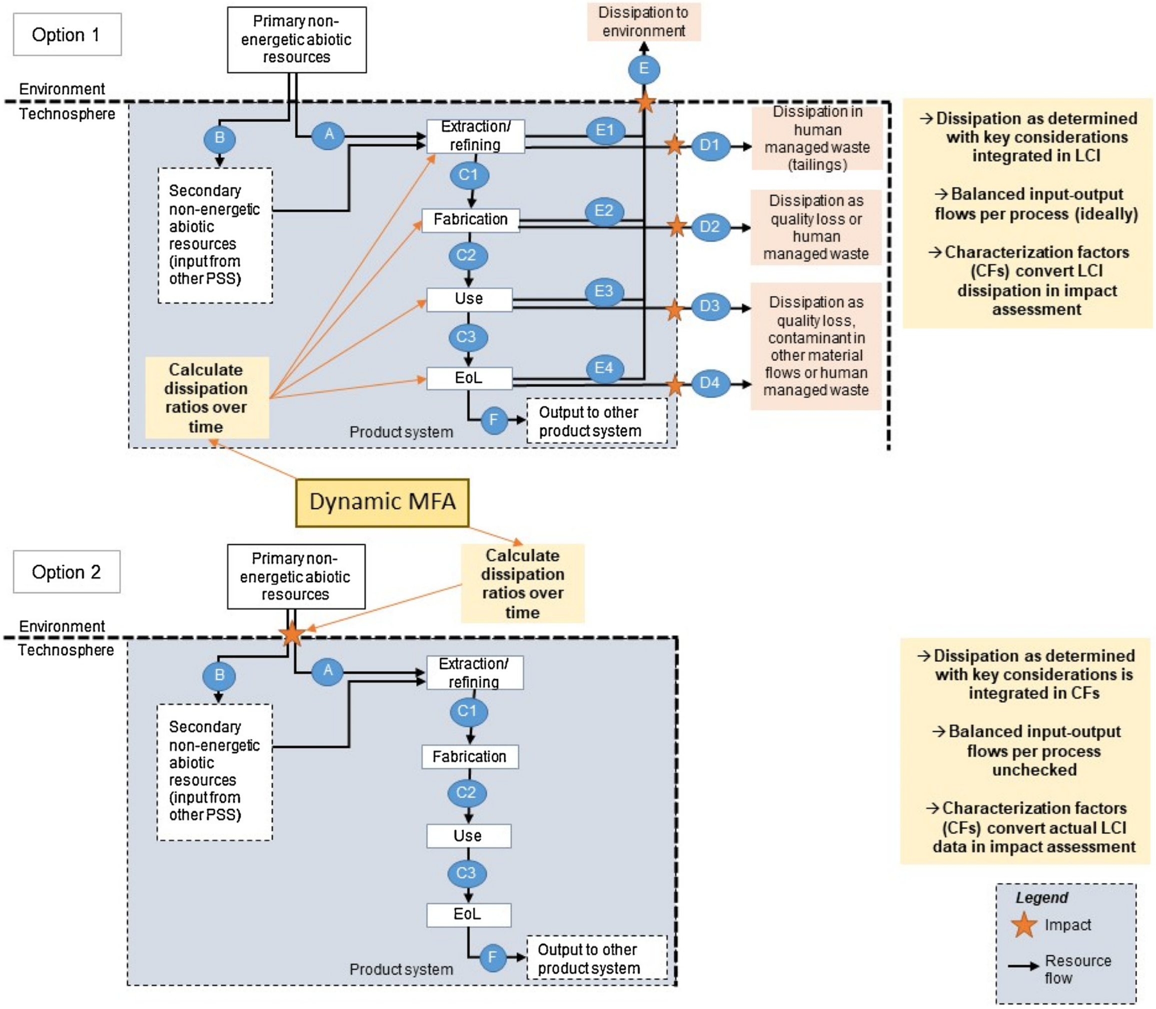

Fig. 1. Two options for the modelling of dissipative flows in LCA based on a simplified resource-centric viewpoint using dMFA. Option 1 uses dMFA to update or create new LCIs and to compute CFs for the AoPs Human Health and Natural Environment by established methods. Option 2 uses dMFA to develop new CFs for the AoP Natural Resources.

Environment with proper CFs in the LCIA phase (Option 1);

2 The integration of such mechanisms directly into CFs related to the AoP of Natural Resources based on more generic resource-based dissipation curves for product systems aggregated by product type, industrial sector or at a geographic level such as global or regional (Option 2).

In both options, flows for one abiotic resource are represented in a simplified theoretical product system. Input flows to the product system include both primary elementary flows (A) and secondary (B) resources. Intermediate resource flows within the product system are marked as C1, C2 and C3. In Option 1, output flows from the product system are distinguished in 3 different fractions: dissipated to other material flows and human managed waste (D), dissipated to environment (E), and looped into other product systems (F). D1 to D4 flows are not elementary flows, as they do not cross the technosphere-environment boundary, but still reside in technosphere as unavailable resources, thus impacting the AoP Natural Resources.

Option 1 allows for mass balance check for every process separately and for the system, as well as to link new inventories to dissipation to other impact categories. Option 2 implies a loss of information about where resources are lost over the life cycle, and it would not enable to compare between different systems using a same resource in different ways if a global scale is chosen. However, Option 2 can be seen as a prevention indicator for abiotic resource use since it anticipates potential quality losses and dissipative flows over a resource's life time that at one moment are not available anymore for recycling and that might lead to environmental impacts within a defined time frame. The two options are not mutually exclusive: they could be combined and also complemented with other data in order to optimize among the precision of the characterization, data availability, and the feasibility of implementation of the proposed functional dissipation approach in LCA. Indeed, different product-specific phases of the life cycle present product system-dependent dissipation patterns. These could be complemented with external data from resource sub-system studies such as the regionally-linked dMFAs study for different aluminium products completed by Bertram et al. (2017).

The proposed approach accounts only for the impacts of the use of abiotic resources, which potentially hampers the functionality for human beings of current and future generations and limits its recycling potential. Moreover, it provides more detailed information about where resources are lost, in particular to the ecosphere over the whole life cycle (Zampori and Sala, 2017), which allows to better anticipate potential environmental impacts. All these aspects offer important arguments to apply the functional dissipation approach and might facilitate its uptake, once implemented, in characterizing the impacts of non-energetic abiotic resource use in complementarity to depletion modelling.

Beyond the proper consideration of non-energetic abiotic resource use in LCA, the proposed functional dissipation approach using dMFA data could also be applied in the future to address other resource consumption related challenges in LCA, such as the use of fossil fuels for plastics that has led to marine litter pollution, and the accumulation of space debris in orbits around the earth, currently not adequately taken into account in LCA. The phenomena leading to impacts is always the same: missing anticipation by humans of the potential damages due to dissipation of materials in natural reservoirs.

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