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The Risk of Earth Destabilization (RED) index, aggregating the impact we make and what the planet can take

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A B S T R A C T

The current golden standard for calculating the environmental impact of a product or process is the Life Cycle Assessment (LCA) approach, leading to results in a large number of impact categories, such as climate change, acidification and toxicity. In the absence of information on which impact category to prioritize, alike products cannot easily be compared and judging environmental sustainability remains difficult. To facilitate transparent communication about the sustainability of products and processes to all members in society, we present a novel environmental index: the Risk of Earth Destabilization (RED) index. Using weighting factors based on the Planetary Boundaries framework, the index takes into account the “planetary urgency”, and hence the risk of earth destabilization associated with each of the LCA impacts. The methodology proposed further refines the work done by Tuomisto et al. (2012), thereby contributing to the ongoing efforts within the EU Environmental Product Footprint project for developing weighting factors and building single score indices. A case study on meat consumption options (beef, pork, poultry) illustrates the broad applicability of the RED index and visualization options.

1. Introduction

Citizens and policy makers are increasingly concerned with the environmental impacts associated with the goods we consume. Ecological burdens and human health impacts connected with the entire product life cycle can be calculated using the Life Cycle Assessment (LCA) approach (ISO, 2006a, 2006b). After compiling a life cycle inventory, inventory data are multiplied with characterization factors, resulting in impact indicator results. This can be done at either the midpoint level where the categories focus on a single environmental problem such as climate change, acidification or human toxicity, at the endpoint level where the impacts express damages done to areas of protection such as human health or natural resources, or through a combination of both whereby the inventory is first characterized into midpoint impacts and then subsequently characterized into endpoint impacts (Hauschild et al., 2013).

Interpretation of a collection of midpoint or endpoint impacts may not always be straightforward. As such, for communication purposes, LCA results can be converted into a single environmental index. Impacts are therefore first normalized to frame its relative magnitude by presenting them relative to reference impacts, such as the impact of one person living in Europe (Benini et al., 2014; Bjørn and Hauschild, 2015; Brentrup et al., 2004; Sleeswijk et al., 2008). Next, to take into account the potential harm to the environment, the dimensionless normalized impacts are multiplied with weighting factors, after which they are aggregated into a single index (Brentrup et al., 2004).

The last decades, several life cycle impact assessment methods (LCIA) have been proposed, each of them having its own set of midpoints and/or endpoint characterization factors, with many of them being complemented with normalization and weighting factors as described by the EU Joint Research Centre (EC-JRC, 2010) and Pré (2017). In 2013, the European Product Environmental Footprint (PEF) pilot phase was set up, aiming at providing consumers with harmonized information on the environmental performance of products. Within this project, the International Reference Life Cycle Data System (ILCD) is put forward as LCIA method to calculate the impacts associated with a specific product (category), leading to results expressed in 16 midpoint ICs, of which one is an interim category (EC-JRC, 2011; European Commission, 2013; Hauschild et al., 2013). The pilot phase further entailed testing of normalization and weighting factors for the midpoint impacts (European Commission, 2016a, 2016b). In the meantime, normalization factors have been determined (European

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Commission, 2016a) whereas weighting factors are currently being investigated (Benini et al., 2015).

The present study contributes to this ongoing process by proposing weighting factors which convert LCA results, expressed in ILCD impact categories, into a new environmental index called "the Risk of Earth Destabilization (RED) index". The index and its associated weighting factors hereby comply with the following essential requirements. Firstly, the index should facilitate interpretation and evaluation of LCA midpoint impact results (LCA output) as found in current and future scientific LCA literature and databases. Details on the inventory phase are typically not available in existing LCA literature and therefore the index should only rely upon the LCA output. Secondly, the weighting factors used should be based on scientifically valid targets, building on recent developments on measuring risk of earth destabilization, namely the concept of Planetary Boundaries (PB).

The Planetary Boundaries (PB) framework defines a safe operating space for humanity with respect to the earth system through the identification of control variables and planetary boundaries for nine key earth system processes (Rockström et al., 2009a, 2009b; Steffen et al., 2015). For each control variable, a threshold or boundary is set which should not be passed in order to maintain a resilient earth system, combining both upper limits (maximum thresholds) and lower limits (minimum limits). Additionally, for each PB, a zone of uncertainty was identified which captures both gaps and weaknesses in the scientific knowledge base and intrinsic uncertainties in the functioning of the earth system. For four of the earth system processes (climate change, change in biosphere integrity, biogeochemical flows, and land-system change), the anthropogenic perturbation levels have already trespassed the proposed global boundary values (Rockström et al., 2009a, 2009b; Steffen et al., 2015).

Table 1 provides an overview of the planetary boundaries concept, listing the earth system processes, control variables, planetary boundaries, nature of limit (upper or lower limit) and zones of uncertainty based on Steffen et al. (2015). As indicated in the table, the current perturbation level of an earth system can be considered as "safe" according to Steffen et al. (2015) if the current value of a control value has not trespassed the proposed PB (marked with green). In case the PB is being trespassed but we are still within the zone of uncertainty, we find ourselves in a situation of "increased risk" of irreversibly driving the earth into a less hospitable state (marked with orange). Lastly, in case the current value of the control variable has also trespassed the zone of uncertainty of the proposed PB, we are in a situation of "high risk" (marked with red).

In 2017, a study was published on the environmental impacts associated with food and beverages consumption in the EU, making use of an "EU Basket of Products (BoP) for food" (Notarnicola et al., 2017). This basket gathers products that are believed to be representative for food consumption for the year 2010 in Europe. Environmental impacts are calculated on a life-cycle basis, resulting in impacts expressed in a wide range of impact categories. As such, results can at this moment not easily be communicated to the general public. For illustrative purposes, we will therefore apply the RED approach to this study. Furthermore, the case study is used to present a potential visualization approach for the RED index, applicable within the context of food.

2. Material and methods

2.1. Building the index

2.1.1. Linking the PB and LCA frameworks

In the following subsections, we describe, as the first step for building our index, the scientific linkages between the nine earth system processes within the PB framework (as shown in Table 1) with the LCA ICs, and select a relevant set of LCA midpoint impact categories to represent the PB earth system processes and their respective control variables. Following the great stakeholder involvement in the PEF project mentioned in the introduction section, we can expect the methods proposed within the PEF pilot phase, such as the use of the ILCD impact assessment method (European Commission, 2013), to become the standard in Europe for measuring product environmental performance. For this reason, it was decided to use the ILCD framework as our LCA framework, even though it has so far only been used to a limited extent in academic literature.

It is important to note from the onset that the current set of linkages is open for improvement in the future, while keeping the concept of our research (the RED index). An overview of the current linkages can be found in the three left columns of Table 2; the last three columns result from calculations explained in Sections 2.1.2 and 2.1.3.

2.1.1.1. PB earth system processes that could be linked to impact categories (IC) in the LCA framework. **PB Earth system process "Climate Change" & LCA IC "Climate Change".** The PB boundaries relate to atmospheric carbon dioxide (CO_2) concentration and to the energy imbalance of top of the atmosphere, caused by changes in radiative forcing (Rockström et al., 2009a; Steffen et al., 2015). This is strongly related to the climate change IC, which takes into account CO_2 and other greenhouse gases, based on their global warming potential and thus reflecting their radiative forcing ability (Goedkoop et al., 2013). As the PB control variable on radiative forcing is thought to be the more inclusive and fundamental (Steffen et al., 2015), the control variable "energy imbalance of top of the atmosphere" can be linked to the climate change IC.

PB Earth system process "Stratospheric ozone depletion"& LCA IC "Ozone depletion". The boundary is based on the ozone concentration (Rockström et al., 2009a; Steffen et al., 2015) and can be linked to the ozone depletion IC. The other ozone related IC, namely photochemical ozone formation, refers to ground level or tropospheric ozone (summer smog) and is therefore not relevant for this PB.

PB Earth system process "Biogeochemical flows". The three boundaries currently focus on nitrogen (N) and phosphorous (P) inputs (Rockström et al., 2009a; Steffen et al., 2015).

(i) The PB control variable "global-level boundary for P" relates to phosphorous (P) flows from freshwater into the ocean. This boundary can be linked to the **IC marine eutrophication**.
(ii) The PB control variable "regional-level boundary for P" refers to phosphorous flows from fertilizers to erodible soils, which eventually result in phosphorous flows to freshwater. This boundary excludes phosphorous that is being recycled within the agricultural system, such as phosphorous from manure (Steffen et al., 2015). Even though the **IC freshwater eutrophication** does actually include impacts resulting from the application of manure, this category was – for now – considered the best available option for linking the LCA framework with the regional-level boundary for P.
(iii) The PB control variable "global-level boundary for N" refers to intentionally fixed reactive nitrogen (N) in the agricultural system. This includes both industrial fixation related to the production of fertilizers through the Haber-Bosch process and to biological fixation of N such as planting of leguminous crops, while unintended N fixation resulting from combustion related nitrogen oxide emissions in transport and industry is excluded (de Vries et al., 2013; Steffen et al., 2015). Steffen et al. (2015) further decided to focus the nitrogen PB