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# Representativeness of environmental impact assessment methods regarding Life Cycle Inventories

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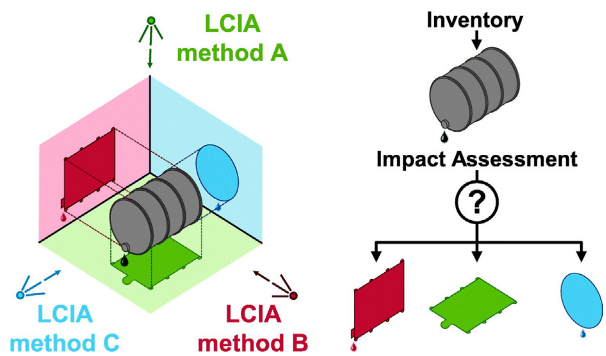
## HIGHLIGHTS

- LCI data describes production systems by their exchanges with the environment
- LCIA methods (environmental issues) are studied as dimensional reduction techniques
- The Representativeness Index (RI) assesses the adequacy of LCIA methods for LCIs
- It is an angular distance between LCI and LCIA method or impact category
- The approach is illustrated with 18 LCIA methods over 4 electricity mix production

## GRAPHICAL ABSTRACT

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## ABSTRACT

Life Cycle Assessment (LCA) characterises all the exchanges between human driven activities and the environment, thus representing a powerful approach for tackling the environmental impact of a production system. However, LCA practitioners must still choose the appropriate Life Cycle Impact Assessment (LCIA) method to use and are expected to justify this choice: impacts should be relevant facing the concerns of the study and misrepresentations should be avoided. This work aids practitioners in evaluating the adequacy between the assessed environmental issues and studied production system. Based on a geometrical standpoint of LCA framework, Life Cycle Inventories (LCIs) and LCIA methods were localized in the vector space spanned by elementary flows. A proximity measurement, the Representativeness Index (RI), is proposed to explore the relationship between those datasets (LCIs and LCIA methods) through an angular distance. RIs highlight LCIA methods that measure issues for which the LCI can be particularly harmful. A high RI indicates a close proximity between a LCI and a LCIA method, and highlights a better representation of the elementary flows by the LCIA method. To illustrate the benefits of the proposed approach, representativeness of LCIA methods regarding four electricity mix production LCIs from the ecoinvent database are presented. RIs for 18 LCIA methods (accounting for a total of 232 impact categories) were calculated on these LCIs and the relevance of the methods are discussed. RIs prove to be a criterion for distinguishing the different LCIA methods and could thus be employed by practitioners for deeper interpretations of LCIA results.



## 1. Introduction

The LCA methodology provides a standardized and commonly used framework to quantify the environmental impacts of human activities

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(ISO, 2006a, 2006b). In the four-step framework of the LCA, beginning with the goal and scope and ending with the interpretation, the main steps are the Life Cycle Inventory (LCI) and the Life Cycle Impact Assessment (LCIA). LCI describes a production system throughout the value chain and quantifies all emission flows to the environment as well as all resource consumption flows (all defined as elementary flows). At the LCIA level, by means of linear-weighted aggregations using Characterization Factors (CFs), elementary flows are translated in terms of environmental impacts such as climate change, depletion of resources, acidification, ionizing radiation or human toxicity…

LCIA methods are associated to ready-to-use sets of impact categories (EC-JRC, 2010a). Impact categories of LCIA methods rely on the characterization models of the environmental issues. The environmental relevance and the scientific validity of the characterization models are constantly challenged to update the best practice (Hauschild et al., 2013; Udo de Haes et al., 1999; Rack et al., 2013; Bare and Gloria, 2006; Huijbregts et al., 2016). The use of different LCIA methods may then lead to disparate results (Dreyer et al., 2003; Owsianiak et al., 2014; Monteiro and Freire, 2012; Pizzol et al., 2011). Owsianiak et al. (2014) showed that disagreements in LCIA results are mainly due to differences in the underlying characterization model, in substance coverage, in relative ranking of the reference substance or due to different spatial or time scales. LCA practitioners often choose a LCIA method (or a subset of impact category proposed by a LCIA method) according to (i) existing guidelines bearing the latest update of LCIA methods, (ii) the context and the user needs guided by the goal and scope of the LCA study, (iii) the modelling choice of the method (the intended purpose, the problem or damage-oriented approach, the covered impacts, the regional and temporal validity of the method…) but also (iv) the habits and the expertise of the LCA practitioner (ISO, 2006a; EC-JRC, 2011; Laurent et al., 2014).

From a data analysis point of view, LCIA reduces the complexity of systems described at LCI level from several hundred variables (high-dimensional dataset of elementary flows, which makes it difficult to fully apprehend the comparison), to a reduced number of criteria for which systems are described by their performance on a few environmental impact categories (low-dimensional dataset, allowing an easier comparison). LCIA can be viewed as a dimensional reduction technique, inherently linked with information losses, but where each of the resulting dimensions has an environmental meaning.

The aim of this work is to help practitioners select the most appropriate LCIA method with regard to the studied LCIs. The selection of impact categories was examined over a large range of products and impact categories by Steinmann et al. (2016). Based on the maximum amount of variance of results from the impact categories, Principal Component Analysis has highlighted an optimal set of impact categories derived from different LCIA methods. In this paper, a Representativeness Index (RI) is proposed to assess how LCI information can be captured by the LCIA methods and their own impact categories. This RI does not measure the relevance of the environmental model behind the LCIA methods. It rather offers the possibility to obtain an objective appraisal of LCIA methods with additional information on the completeness representation of inventories they actually perform and can contribute to result interpretation. This paper is organized as follows: in Section 2, the RI is defined and the algorithm developed from a geometric representation of LCA is presented. This approach is illustrated in Section 3 on classic LCIA methods for several electricity mix productions from the ecoinvent database (Moreno Ruiz et al., 2013). Finally, representativeness of impact categories are presented for two electricity mixes through a single LCIA method in order to deepen the interpretation of the RIs.

## 2. Material and method

The proximity relationship between a LCI and impact category vectors can be studied thanks to the geometrical interpretation of LCA methodology. The proximity measurement—also called Representativeness Index (RI) in the following—is defined and adjusted according to the impact category vector as well as to vector sub-spaces generated by sets of impact category vectors (LCIA methods). The implementation is then presented.

### 2.1. Geometrical representation of LCA methodology

#### 2.1.1. Life Cycle Inventories

LCI is classically defined in LCA as an inventory vector resulting from the computation of the final demand vector, the technology matrix and the intervention matrix (Heijungs and Sangwon, 2002). This aggregated LCI consists in the quantification of $n$ elementary flows, resulting from emissions into the environment and resource extractions, over the whole process tree (the involved life cycle steps). This aggregated LCI belongs to a $K$ space of $n$ dimensions where $n$ is the number of different elementary flows. The visualization of LCI in a vector space generated by an elementary flow basis has previously been suggested by Le Téno (1999) and Heijungs and Sangwon (2002). Therefore any LCI can be localized in this $\mathbb{R}^n$ vector space either as a simple data point $k$ or as a data vector $k$ with $n$ coordinates $k_i$ ($i \in \{1, 2, \ldots, n\}$). The norm of the LCI vector is directly linked to the reference flow of its functional unit (e.g. the norm of one kilogram of a given product is one thousand times greater than the norm of one gram of the same given product). The direction of the LCI depends on the relative proportion of the elementary flows. As a simple illustration, Fig. 1a represents two LCI, $a$ and $b$, described by two elementary flows (i.e. into a 2-dimensional space, here $NO_2$ and $NH_3$ gas emissions).

#### 2.1.2. Impact categories

The impact categories are the environmental issues used to characterize, assess and compare production systems. For each impact category (e.g. climate change, particulate matter or resource depletion…), a category indicator is defined (e.g. $CO_2$ equivalent, PM 2.5 equivalent or antimony equivalent). Elementary flows of the LCI are converted into a corresponding amount of the category indicator by means of CFs. CF values result from the modelling of environmental concerns and, for a given environmental concern, all related CFs form the characterization model of its corresponding impact category. A $j$ characterization model is then a $f_j$ function that associates a $k$ LCI vector to a $h_{j,k}$ one-dimensional impact result expressed as a category indicator:

$$f_j : \begin{cases} K \rightarrow H \\ k \rightarrow h \end{cases} \qquad (1)$$
$$h_{j,k} = f_j(k) = \sum_{i=1}^{n} f_{i,j} \times k_i$$

where $f_{j,i}$ is the CF for $i$-th elementary flow.

In mathematical terms, the linear-weighted aggregation performed by an impact category corresponds to a linear form that maps a $K$ vector space to a scalar. The $K^*$ dual space is the n-dimensional vector space of all the linear forms $f: K \rightarrow \mathbb{R}$. Independently of their environmental meaning, all the characterization models determined by their CFs $f_{i,j}$ ($i \in \{1, 2, \ldots, n\}$) belong to the dual space. LCI and characterization models belong to $K$ and its $K^*$ dual space, respectively. According to the Fréchet-Riesz theorem, a linear form $f$ of $K^*$ can be represented by a unique vector within $K$. The characterization model of an impact category can therefore be associated with a vector of the $K$ space using the CFs as coordinates. As a simple illustration, Fig. 1b shows two impact categories, particulate matter formation and acidification, in the inventory space. For the sake of simplification, the term "characterization model of impact categories" will from now on be referred to as the "impact category vector". Also, the same notation $f$ will be applied for the impact category vector transferred from $K^*$ to $K$.

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