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Coupling material circularity indicators and life cycle based indicators: A proposal to advance the assessment of circular economy strategies at the product level

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ABSTRACT

The debate on the identification of the most suited metrics for circular economy (CE) is open, no consensus has been reached yet on what CE indicators at product level should measure, which creates a subjective methodological framework for assessing CE strategies. In this study, we demonstrate that by coupling different types of indicators via Multi Criteria Decision Analysis (MCDA) it is possible to deal with conflicting situations where the selection of the best alternative can be biased by the choice of the metric. We use a beer packaging case, by simulating a situation where a company is interested in comparing the performances of different packaging from a CE perspective. We consider eight different beer packaging alternatives in two geographical contexts (United Kingdom and India). Two sets of indicators are coupled via MCDA: i) material circularity based- indicators, namely Material Reutilization Score and Material Circularity Indicator, and ii) a selection of life cycle based-indicators relevant for beer, i.e. climate change, abiotic resource depletion, acidification, particulate matter and water consumption. The results obtained by the application of the TOPSIS (Technique for Order by Similarity to Ideal Solution) method show that the different sets of indicators can be integrated and conflicts among them can be resolved. Overall, the application of different weighting scenarios does not change the ranking of the alternatives, thus confirming that the results are stable. Therefore, our proposal of coupling material circularity indicators with LCA indicators via MCDA can advance the assessment of CE strategies at the product level.

1. Introduction

The scientific debate on circular economy (CE) conceptualization and implementation has recently intensified (Babbitt et al., 2018; Bocken et al., 2017). An agreement on what the CE concept exactly mean is still missing and many definitions have been proposed by scholars (e.g. Blomsma and Brennan, 2017; Geissdoerfer et al., 2017; Homrich et al., 2018; Kirchherr et al., 2017; Korhonen et al., 2018). From a standardization point of view, the British Standard Institute released in May 2017 the BS 8001:2017 standard titled "*Framework for implementing the principles of the circular economy in organizations - Guide*". This is the first standard that aims to provide guidelines to organizations in the transition towards a more circular and sustainable mode of operation by drawing on the experiences and lessons learned from a range of organizations already involved with CE implementation. According to BS 8001:20,017 CE is "*an economy that is restorative and regenerative by design, and which aims to keep products, components and materials at their highest utility and value at all times, distinguishing*

Abbreviation List: A1, alternative 1; A2, alternative 2; A3, alternative 3; A4, alternative 4; AC, acidification; AlC, aluminium can; ARD, abiotic resource depletion; BS, British Standard; C2C, Cradle to Cradle®design framework; CC, climate change; CE, circular economy; CEIP, circular economy indicator prototype; CET, circular economy toolkit; EMF, Ellen MacArthur Foundation; EoL, end-of-life; FMCG, fast moving consumer goods; ILCD, international reference life cycle-data system; IN, India; IR, intrinsic recyclability; LCA, life cycle assessment; LCIA, life cycle impact assessment; MCDA, multi-criteria decision analysis; MCI, material circularity indicator; MFCA, material flow cost accounting; MRS, material reutilization score; NIS, negative ideal solution; OWGB, one-way glass bottle; PEF, product environmental footprint; PEFCR, product environmental footprint category rules (PEFCR); PIS, positive ideal solution; PM, particulate matter; RC, recycled content; RCR, recycling collection rate; ReR, reuse rate; RGB, refillable glass bottle; S1, scenario n.1; S2, scenario n.2; S3, scenario n.3; S4, scenario n.4; S5, scenario n.5; SK, steel keg; TOPSIS, technique for order by similarity to ideal solution; UK, United Kingdom; WC, water consumption

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between technical and biological cycles" (British Standard, 2018). Such definition is highly inspired by the Ellen Mac Arthur Foundation (EMF) formulations of the concept (EMF and Granta Design, 2015; EMF, 2015, 2013), with an emphasis on the distinction between the two cycles (biological and technical), which is derived by the Cradle to Cradle® (C2C) design framework (Braungart and Engelfried, 1992). As outlined in the monitoring framework for a circular economy "*The transition to a circular economy is a tremendous opportunity to transform our economy and make it more sustainable, contribute to climate goals and the preservation of the world's resources, create local jobs and generate competitive advantages for Europe in a world that is undergoing profound changes*" (European Commission, 2018). Therefore, there is a huge potential for contributing to the achievement of the Greenhouse Gases (GHG) emission reduction targets defined by the Paris Agreement (United Nations, 2015) by implementing the CE concept and monitoring its progress. The guidance provided by BS 8001:2017 is useful on the conceptual level through the identification of CE principles and strategies, but it is lacking on the operational and implementation level (Niero and Schmidt-Rivera, 2018; Pauliuk, 2018). According to BS 8001:2017 standard, the responsibility of choosing the appropriate CE performance indicators is borne by the organization implementing CE (Pauliuk, 2018). The debate on the identification of the most suited metrics for CE is very much open, no consensus has been reached yet which creates a subjective methodological framework for assessing CE.

Most of the available indicators measuring CE strategies refer to the macro (i.e. region, nation, sector) and meso levels (i.e. eco-industrial parks) and not to the product level scale (Linder et al., 2017). There are contrasting opinions among scholars on what CE indicators at product level should measure and whether indicators addressing single or multiple issues are more suited. Linder et al. (2017) recommend that a circularity metric at the product level should focus exclusively on measuring circularity, i.e. the fraction of a product that comes from used products, as a single attribute of product quality and not on environmental performance or competitiveness. Pauliuk (2018) provides, instead, a dashboard of new and established indicators for the quantitative assessment of CE for product systems and organizations. Such list addresses different categories of indicators, measuring both physical circularity, monetary value, and potential environmental impacts, mostly based on material flow analysis (MFA), material flow cost accounting (MFCA) and life cycle assessment (LCA). Saidani et al. (2017) criticized the ability of three existing approaches, i.e. Material Circularity Indicator (MCI) (EMF and Granta Design, 2015), Circular Economy Toolkit (CET) (Evans and Bocken, 2013) and Circular Economy Indicator Prototype (CEIP) (Griffiths and Cayzer, 2016), to measure product circularity performance both in terms of their applicability in industry and their accordance with CE principles. However, they also acknowledged that different indicators serve different purposes and some tools could be better in one situation, such as comparing rapidly the impact of two different materials on circularity performance, e.g., the MCI (EMF and Granta Design, 2015), meanwhile others are more product-centric and lifecycle thinking oriented. The relevance of using indicators based on life cycle thinking, such as carbon footprint, to complement material efficiency-based indicators has been demonstrated in the case of aluminium cans (Niero and Hauschild, 2017a), tidal energy device (Walker et al., 2018) and tyres end-of-life management (Lonca et al., 2018). LCA is based on the eco-efficiency concept, which focus on the optimisation of individual product systems, leading not only to a reduction in resource consumption and pollution, but also to the potential risk of optimizing inherently unsustainable systems, such as waste incineration in Denmark (Bjørn and Hauschild, 2013). Hence, an overall assessment of the environmental sustainability of product system needs coupling of indicators addressing complementary aspects, such as material circularity and performance from eco-efficiency (e.g. LCA indicators). The Multi-Criteria Decision Analysis (MCDA) framework can fit the purpose of addressing the multiple dimensions of circularity indicators and its use has therefore been advocated (Niero and Hauschild, 2017b; Seager and Linkov, 2008). The MCDA comprise a set of methods based on various mathematical principles used to resolve conflicting objectives (Halog and Manik, 2011). It has been widely applied in various disciplines for decision making, e.g. to select the most sustainable stormwater management alternative in developing countries (Gogate et al., 2017), to determine a set of good alternative(s) for concrete production, considering environmental and economic criteria (Suárez Silgado et al., 2018) or for alternative screening and ranking in the waste management sector (Pires et al., 2011).

To the best of our knowledge, no previous study has coupled different indicators to measure the CE performances at any level (macro, meso or micro) via MCDA. At the product (i.e. micro) level the use of different types of indicators to assess CE performances has been tested in only a limited set of sectors, such as energy (Saidani et al., 2017), manufacturing (Walker et al., 2018) and packaging (Niero and Hauschild, 2017a), but only one type of product per time has been included in the analysis. Moreover, a lack of references to sustainability performance indicators or assessment methodologies with regard to CE activities was found in the analysis of corporate sustainability reports in the Fast Moving Consumer Goods (FMCG) performed by Stewart and Niero (2018). Only a limited number of companies present a dedicated set of key performance indicators for their CE approach, based on either metrics addressing material efficiency, LCA results or use of the C2C certification program. The present study focuses on the packaging sector, i.e. a sector with high priority for CE implementation (EC, 2015a; EMF, 2013). We contribute to advancing the assessment of CE strategies by simulating a situation where a company is interested in comparing the performances of different packaging from a CE perspective. The novel approach of coupling different circularity indicators with LCA based indicators by means of MCDA is proposed, which enables capturing the performance of the product system from both CE and eco-efficiency perspectives.

2. Materials and methods

We present an illustrative case where different material circularity indicators (Section 2.1) and life cycle based indicators (Section 2.2) are coupled via MCDA (as described in Section 2.3) in a case study including different beer packaging alternatives in two geographical contexts (Section 2.4).

2.1. Material circularity based-indicators

In the selection of the material circularity indicators addressing the product level assessment, we prioritized two indicators that are aimed to be used within a company context (Linder et al., 2017), developed by two of the most influential actors in framing and spreading the CE concept among businesses, i.e. proponents of the C2C design framework and the EMF. The selected indicators are the Material Reutilization Score (MRS) and the above-mentioned MCI.

The MRS is the metric used to quantify material reutilization, i.e. the criterion included in the C2C certification program addressing the recycling value of the materials (Cradle to Cradle Products Innovation Institute, 2016). With regard to the technical cycle, the MRS quantifies the recyclability potential of a product considering two variables: the intrinsic recyclability (IR) of the product, i.e. the % of the product that can be recycled at least once after its initial use stage and the % recycled content (RC). The MRS is given by the weighted average of the two variables, where the first one is given twice the weight of the second one, as reported in Eq. 1, with a final value ranging from 0 to 100.

$$\text{MRS} = [(\%\ \text{IR of the product})\cdot 2] + [(\%\ \text{RC } \textit{in the product})\cdot 1] \ / \ 3\cdot 100 \quad (1)$$