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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

Monia Niero⁎, Pradip P. Kalbar

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.

Keywords:
Multi criteria decision analysis
Life cycle assessment
Circular economy
TOPSIS
Packaging
Circularity indicators

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., 2015; 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 8001:2017 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; AA, 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

⁎ Corresponding author.
E-mail address: monian@plan.aau.dk (M. Niero).

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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 contrib-
tuting 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 perfor-
mance 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 en-
vironmental performance or competitiveness. Pauliuk (2018) provides,
instead, a dashboard of new and established indicators for the quanti-
tative 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 ac-
counting (MFCA) and life cycle assessment (LCA). Saidani et al. (2017)
criticized the ability of three existing approaches, i.e. Material Circu-
ularity 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 ap-
plicability in industry and their accordance with CE principles. How-
ever, 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 pro-
duct 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 environ-
mental 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-Cri-
teria Decision Analysis (MCDA) framework can fit the purpose of ad-
dressing 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 man-
agement alternative in developing countries (Gogate et al., 2017), to
determine a set of good alternative(s) for concrete production, con-
sidering environmental and economic criteria (Suárez Silgado et al.,
2018) or for alternative screening and ranking in the waste manage-
ment sector (Pires et al., 2011).
To the best of our knowledge, no previous study has coupled dif-
ferent 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),
multi-packaging (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 sustainabil-
ity 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 per-
spective. The novel approach of coupling different circularity indicators
with LCA based indicators by means of MCDA is proposed, which en-
ables 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 in-
cluding 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 % re-
cycled 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.

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

(1)
The MCI is the main index developed by the EMF and Granta in the context of the MCI Project aiming to find indicators to measure how well a product performs in the CE context (EMF and Granta Design, 2015). It provides an indication of how much a product’s materials circulate, ranging from 0 to 1, in order to allow companies to understand how far they are on the transition from ‘linear’ to ‘circular’ (EMF and Granta Design, 2015). The MCI is essentially constructed from a combination of three product characteristics: the mass of virgin raw material used in manufacture, the mass of unrecoverable waste that is attributed to the product, and a utility factor that accounts for the length and intensity of the product’s use. The parameters used to calculate the MCI refer to: i) destination after use, distinguishing among the percentages of recycling collection rate (RCR) and reuse rate (RR); ii) percentage of recycled feedstock (RC); iii) efficiency of the recycling process, i.e. the yield during recycling, and iv) utility during use stage, i.e. use intensity with regard to an average product in the market. The MCI Dynamic Modelling tool provided by Granta has been used to perform the calculation of MCI (https://www.ellenmacarthurfoundation.org/programmes/insight/circularity-indicators).

### 2.2. Life cycle based-indicators

By life cycle based-indicators we refer to the life cycle impact categories indicators that are obtained from LCA. The selection of the most relevant impact categories to include in an LCA has been highly debated in the scientific literature, including its dependency on the sector of study (Kalbar et al., 2018, 2017a; Steinmann et al., 2016; Van Hoof et al., 2013). Product Environmental Footprint Category Rules (PEFCR) in the context of the PEF pilots initiative aims to ensure that LCA is carried out focusing on significant contributors (foreground and background processes) in life cycle stages, and relevant impact categories for the sector (Galatola and Pant, 2014). Therefore, we decided to select one product category for which PEFCR are available and for which packaging represents a contributing life cycle stage. We selected beer, where the influence of different packaging types is known to be relevant in terms of environmental performances (Amienyo and Azapagic, 2016; Cimini and Moresi, 2016). Thus, for the selection of the life cycle-based indicators, we focused on the most relevant impact categories listed in the final version of the PEFCR of beer (The Brewers of Europe, 2018), i.e. climate change, particulate matter, acidification, resource use (mineral and metals; fossil) and water use. Packaging and material production represent indeed (one of) the most relevant life cycle stage contributing to the impacts for climate change, respiratory inorganic, acidification terrestrial and freshwater, water scarcity, and resource use (both energy carrier and minerals and metals) (see Table 9 in The Brewers of Europe, 2018). The calculation of the life cycle-based indicators has been performed by means of the Instant LCA Packaging™ version 1.15.2 provided by RDC Environment, i.e. a customized software used by industry for packaging LCA, which has already been used to perform LCA on beverage packaging (Niero et al., 2016). The functional unit considered by the software is the containment and packaging of 1 hectolitre (hl) of beer. System boundaries of this LCA was limited to the production of primary packaging, to take into account only the materials and align the calculations with the material circularity indicators, thus excluding also the transport between different stage of life cycle (producer, consumer, recycler). The Life Cycle Impact Assessment (LCIA) methodology implemented in the software used refer to the International Reference Life Cycle-Data System (ILCD) recommended method (Hauschild et al., 2013), including the following impact categories: climate change (CC, kg CO₂eq), abiotic resource depletion (ARD, kg Sr(eq), acidification (AC, mol H₂), particulate matter (PM, kg PM 2.5eq), water consumption (WC, m³).

### 2.3. Multi Criteria Decision Analysis and weighting sets

MCDA is most commonly used for addressing multiple conflicting objectives. Many methods can be used for MCDA: Greco et al. (2016) provides a review of the available methods. The use of compensatory and non-compensatory approach makes the major difference in the MCDA methods. In compensatory approaches the trade-off between the indicators is allowed, whereas non-compensatory approaches are usually based on outranking principles which use pairwise comparison of alternatives (Seppälä et al., 2001). Guitouni and Martel (1998) provides detailed guidelines for choosing the appropriate MCDA method for the particular decision problem. Based on these guidelines and analysis of similar decision contexts (Behzadian et al., 2012; Pires et al., 2011; Sohn et al., 2017), we have found that the TOPSIS (Technique for Order by Similarity to Ideal Solution) method is best suited for the problem being addressed in this work. The TOPSIS method uses Euclidian distance measure for identifying the alternative from the Positive Ideal Solution (PIS) and Negative Ideal Solution (NIS). PIS is basically a hypothetical alternative formulated using the highest score of the indicators in case of benefit type indicators (i.e. material circularity indicators) and lowest score of the indicators in case of cost type indicators (i.e. LCA indicators). Similarly, NIS is also a hypothetical alternative formulated using opposite logic that of PIS. In TOPSIS the alternative which is nearer to the PIS (i.e. resembles characteristic of PIS) and farther from the NIS receives the highest score (calculated using Euclidian distance measure). A detailed methodology of TOPSIS specific to processing of LCA indicators can be found in Kalbar et al. (2017b).

In MCDA indicator weights significantly influences the final ranks of the alternative and hence Kalbar et al. (2012) proposed a scenario-based decision making approach to properly structure the decision making problem. The scenarios describe the stakeholder’s perspectives in terms of weights and final rankings can be obtained for each of the scenario, which reflect the stakeholders’ preferences more correctly. Considering this, we have defined five scenarios (S1-SS) representing the varying weights to each type of indicator representing various stakeholders’ preferences (see Table 1). For example, in Scenario 1 (S1) equal weightage is given to all the indicators, whereas in Scenario 2 (S2) higher weightage is given to material circularity indicators. These weighting schemes are used to rank the various alternatives of the case study described in the next section.

### 2.4. Case study: beer packaging

We considered 8 packaging alternatives for beer in two geographical contexts, the United Kingdom (UK) and India (IN), addressing

| Table 1 | Overview of the five scenarios (S1-SS) considered and associated weights assigned to each indicator. |
|---|---|---|---|---|---|---|---|---|
| S1 | 0.143 | 0.143 | 0.143 | 0.143 | 0.143 | 0.143 |
| S2 | 0.200 | 0.200 | 0.150 | 0.150 | 0.100 | 0.100 |
| S3 | 0.100 | 0.100 | 0.150 | 0.150 | 0.200 | 0.200 |
| S4 | 0.100 | 0.100 | 0.200 | 0.200 | 0.150 | 0.150 |
| S5 | 0.200 | 0.200 | 0.200 | 0.100 | 0.100 | 0.100 |

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different materials and packaging sizes. The list of packaging considered is reported in Table 2, for UK: i) 50 l steel keg (SK); ii) 44 centilitre (cl) aluminium can (AlC); iii) 50 cl AlC; iv) 33 cl one-way glass bottle (OWGB); and for India: i) 65 cl refillable glass bottle (RGB); ii) 33 cl RGB; iii) 33 cl AlC; iv) 50 cl AlC. The input data used to calculate the material circularity based- (MRS and MCI) and life cycle based-indicators (i.e. recycled content (%RC) and intrinsic recyclability (%IR); Material Circularity Indicator (MCI), i.e. Material Reutilization Score (MRS), i.e. recycled content (%RC) and intrinsic recyclability (%IR); Material Circularity Indicator (MCI), i.e. Material Reutilization Score (MRS), and destination at disposal (%incineration with energy recovery and % going to landfill) for the selected packaging: SK (steel keg), AlC (aluminium can), OWGB (one-way glass bottle), RGB (refillable glass bottle) in the United Kingdom (UK) and India (IN).

### Table 2

<table>
<thead>
<tr>
<th>Packaging ID</th>
<th>UK</th>
<th>UK</th>
<th>UK</th>
<th>UK</th>
<th>IN</th>
<th>IN</th>
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<tr>
<td>(size)</td>
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</tr>
<tr>
<td>SK (50 l)</td>
<td>A1</td>
<td>A2</td>
<td>A3</td>
<td>A4</td>
<td>A1</td>
<td>A2</td>
<td>A3</td>
<td>A4</td>
</tr>
<tr>
<td>AlC (44 cl)</td>
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<td>OWGB (33 cl)</td>
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<td></td>
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<tr>
<td>RGB (65 cl)</td>
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<th>Alternative n.</th>
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<td>Plastic</td>
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<td>2.30</td>
<td>2.66</td>
<td>2.00</td>
<td>2.00</td>
<td>2.73</td>
<td>2.22</td>
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<tr>
<td>Aluminium</td>
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<td>11.3</td>
<td>13.0</td>
<td>212</td>
<td>450</td>
<td>280</td>
<td>13.4</td>
<td>10.9</td>
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<td>0°</td>
<td>49°</td>
<td>35°</td>
<td>35°</td>
<td>20°</td>
<td>20°</td>
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<tr>
<td>Glass</td>
<td>60°</td>
<td>63°</td>
<td>63°</td>
<td>61°</td>
<td>64°</td>
<td>64°</td>
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<table>
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<td>Incineration with energy recovery (32.9)</td>
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<tr>
<td>Landfill (93.6)</td>
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<th>ReR [%]</th>
<th>RC [%]</th>
<th>RCR [%]</th>
<th>ReR [%]</th>
<th>RC [%]</th>
<th>RCR [%]</th>
<th>ReR [%]</th>
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<td>SK (50 l)</td>
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<td>96.8</td>
<td>98.8</td>
<td>99</td>
<td>100</td>
<td>100</td>
<td>96.8</td>
<td>96.8</td>
</tr>
<tr>
<td>AlC (44 cl)</td>
<td>84°</td>
<td>97°</td>
<td>97°</td>
<td>100°</td>
<td>100°</td>
<td>97°</td>
<td>97°</td>
<td>97°</td>
</tr>
<tr>
<td>OWGB (33 cl)</td>
<td>98.7</td>
<td>n.a.</td>
<td>n.a.</td>
<td>n.a.</td>
<td>62°</td>
<td>62°</td>
<td>n.a.</td>
<td>n.a.</td>
</tr>
</tbody>
</table>

a No primary data available, thus assumption based on (Technical Secretariat for the Beer Pilot, 2015).
b (Stotz et al., 2017).
c Primary data.
d (The Brewers of Europe, 2018).
e (Ghosh, 2016).
f (Bertram et al., 2017).
g InstantLCA Tool based on Eurostat data (2015).
h (Rigamonti et al., 2009).
i (Niero and Olsen, 2016).
j (Technical Secretariat for the Beer Pilot, 2015).

### 3. Results and discussion

First the results of the stand-alone application of the two sets of indicators are presented (Section 3.1), then the outcomes of the coupling via MCDA is introduced (Section 3.2), and finally perspectives and limitations are outlined (Section 3.3).

#### 3.1. Stand-alone applications of material circularity- vs life cycle-based indicators

The results of the stand-alone application of the two types of indicators, i.e. material circularity based indicators (MRS and MCI) and life cycle based indicators (CC, ARD, AC, PM, WC) are also reported in Table 2. For MRS the parameters needed are: %RC and %IR (calculated considering the percentage of the component of the packaging, i.e. primary packaging and lid/cap that can be recycled after initial use). For MCI the parameters needed are: %RC, %RCR, % ReR, yield during recycling and utility (assumed equal to 1 in all cases). For the life cycle based-indicators the information needed are: mass of the primary packaging and cup/lid, %RC, %RCR, % ReR and destination at disposal (%incineration with energy recovery and % going to landfill).

#### 3.2. Coupling material circularity-based- and life cycle-based- indicators via MCDA

The application of the TOPSIS methodology with different weighting sets (see Table 4) shows that alternative 1 (A1, which is 50 l SK in the UK and the 65 cl RGB in IN) is dominating in all cases, i.e. has higher scores for all the scenarios. With regard to the ranking of the different alternatives, for UK it can be noted that two alternatives (AlC
in 44 cl and 50 cl, i.e. A2 and A3) present almost equal score in the life cycle based-indicators, as well as material circularity indicators (see Table 3) and hence TOPSIS scores display very small differences. For the Indian case, the two alternatives in the middle of the ranking present a remarkable difference in terms of life cycle based-indicators, i.e. 50 cl AlC (A3) has higher impact than 33 cl RGB (A2), see Table 3. The same holds for the material circularity based-indicators, but with opposite ranking, i.e. A2 better than A3 (see Table 3).

The stand-alone application of the material circularity based- and life cycle based- indicators presents a conflict and hence no alternative could be selected. This problem of univocally identifying the best performing alternative is solved by the implementation of the MCDA, clearly able to distinguish that A3 is the second most preferred option in all the weighting scenarios. The ranking obtained using TOPSIS in this case is in accordance with the LCA results. This shows that the influence of material circularity indicators is negligible in the final ranking. Such outcome can be interpreted with the help of Fig. 1, where the weighted normalized scores (obtained using Table 3 after vector normalization and weight multiplication) of the all alternatives for S1 (i.e. equal weighting) are plotted. In Fig. 1, the blue line indicates the PIS scores and green line indicates the NIS scores. The alternative that is closer or which follows the path of PIS is the most preferred alternative and the alternative, which is closer to NIS, is the least preferred alternative. As it can be seen in Fig. 1 (showing results of S1), A1 resembles the pattern of PIS, A4 resembles the NIS, and hence they are identified as best and worst performing alternatives, respectively, in both UK and India case. A2 and A3 in UK case resembles each other and follows the path almost the middle of PIS and NIS and hence received the TOPSIS scores of about 0.6 (refer to Table 4). However, in the Indian case A3 follows the path of PIS more similar than A2 and hence received higher score of 0.639 compared to 0.299 score received by A2 in equal weighting scenario case (S1). This shows that the TOPSIS method with its unique mathematical Euclidian distance approach appropriately penalizes negatively the alternative, which is nearer to NIS and favours the alternative resembling the PIS. This is reflected in the scores obtained for A2 and A3 for the Indian case in all scenarios (see Table 3).

The results obtained by application of MCDA shows that the conflict among the indicators can be resolved when methods such as TOPSIS are applied. Overall, the application of different weighting scenarios does not change the ranking of the alternatives, thus confirming that the results are stable. Our proposal of coupling material circularity indicators with LCA indicators via MCDA demonstrate an advancement in the assessment of CE strategies at the product level.

Table 3

Results of the calculation of the indicators considered in the study: i) material circularity based-indicators: Material Reutilization Score (MRS) ranging from 0 to 100 and Material Circularity Indicator (MCI) ranging from 0 to 1 and ii) life cycle based-indicators: climate change (CC), abiotic resource depletion (ARD), acidification (AC), particulate matter (PM), water consumption (WC) for the selected packaging: SK (steel keg), AlC (aluminium can), OWGB (one-way glass bottle), RGB (refillable glass bottle) in the United Kingdom (UK) and India (IN). The colour coding shows the ranking from the best (green) to the worst (red) alternative.

<table>
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<tr>
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<th>IN</th>
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<td>AIC</td>
<td>OWGB</td>
<td>RGB</td>
<td>RGB</td>
<td>AIC</td>
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</tr>
<tr>
<td>(size)</td>
<td>(50 cl)</td>
<td>(44 cl)</td>
<td>(50cl)</td>
<td>(33cl)</td>
<td>(65cl)</td>
<td>(33cl)</td>
<td>(50cl)</td>
<td>(44cl)</td>
</tr>
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<td>A3</td>
<td>A4</td>
<td>A1</td>
<td>A2</td>
<td>A3</td>
<td>A4</td>
</tr>
<tr>
<td>MRS [-]</td>
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<td>81</td>
<td>81</td>
<td>82</td>
<td>78</td>
<td>78</td>
<td>71</td>
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<tr>
<td>MCI [-]</td>
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<td>0.60</td>
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<td>0.63</td>
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<tr>
<td>CC [kg CO2e/kl]</td>
<td>2.13E+00</td>
<td>2.97E+01</td>
<td>2.93E+01</td>
<td>7.30E+01</td>
<td>3.03E+01</td>
<td>3.82E+01</td>
<td>3.27E+01</td>
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<tr>
<td>ARD [kg Sb/kl]</td>
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<td>2.22E-03</td>
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<td>2.65E-03</td>
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<tr>
<td>AC [m^3/kl]</td>
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<td>1.48E-01</td>
<td>5.09E-01</td>
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<tr>
<td>PM [kg PM2.5/kl]</td>
<td>1.86E-03</td>
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<td>WC [m^3/kl]</td>
<td>1.70E-02</td>
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Table 4

Results obtained from the application of the TOPSIS (Technique for Order by Similarity to Ideal Solution), i.e. ranking in the different weighting scenarios (S1-5) and considering the 4 alternatives (A1-A4) for UK and India (IN) for the selected packaging: SK (steel keg), AlC (aluminium can), OWGB (one-way glass bottle), RGB (refillable glass bottle) in the United Kingdom (UK) and India (IN). The colour coding shows the ranking from the best (green) to the worst (red) alternative.

<table>
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<tr>
<td>SK 50 l</td>
<td>A1</td>
<td>0.941</td>
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<tr>
<td>AIC 50 cl</td>
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<td>0.653</td>
<td>A3</td>
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<tr>
<td>OWGB 33cl</td>
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<td></td>
</tr>
<tr>
<td>RGB 65cl</td>
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<td>AIC 44cl</td>
<td>A3</td>
<td>0.639</td>
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<tr>
<td>AIC 50 cl</td>
<td>A4</td>
<td>0.078</td>
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<td>0.056</td>
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3.3. Perspectives and limitations

Our findings confirm the key role that life cycle thinking and its operative tool (LCA) play in the development of meaningful indicators for the CE with regard to the product level assessment (Elia et al., 2017). The LCA methodology has already proved capable to assess the environmental sustainability of the traditional linear approach for reducing resource use, i.e. resource efficiency (or narrowing resources flows according to Bocken et al. (2016) terminology), see e.g. (Huysman et al., 2015). At the same time, LCA can also assess the main CE approaches defined by Bocken et al. (2016), i.e. slowing resource loops, see e.g. (Bakker et al., 2014) and closing resource loops, see e.g. (Niero and Olsen, 2016). LCA is “by definition” meant to take into account two of the three necessary requirements for a CE strategy to guarantee absolute resource decoupling as listed by Kjaer et al. (2018), i.e. “ensure net resource reduction” and “avoid burden shifting between life cycle stages”. However, although the potential of LCA as a decision support tool towards the evaluation of the environmental sustainability potential of CE approaches has been acknowledged (Haupt and Zschokke, 2017), its actual implementation is still not fully exploited. In the FMCG sector, indeed, most of the companies referring to CE in their corporate sustainability reports in 2016 have reported the use of LCA (and other footprint methodologies) to assess and/or monitor their environmental performances, but with no explicit link to CE activities (Stewart and Niero, 2018). LCA can be used in combination with other CE approaches, such as C2C to assess the environmental performances of C2C certified products (Llorach-Massana et al., 2015) and to quantify the progression in the C2C certification (Niero et al., 2016). Moreover, LCA can be combined with CE indicators, e.g. MCI as suggested by Lonca et al. (2018) to identify trade-offs between increasing material circularity and decreasing environmental burdens. The focus on the quantification of trade-offs issues between different sustainability dimensions connected with CE is crucial for a successful implementation of the concept (Niero and Hauschild, 2017b), as well as addressing the systemic dimension and potential CE rebound effects (Font Vivanco et al., 2018; Zink and Geyer, 2017).

However, due to the lack of consensus on the CE concept and given its different relationships with the sustainability concept (Geissdoerfer et al., 2017), it is essential to be able to assess CE strategies by means of indicators addressing several aspects. As we have shown, the MCDA methodology provides a key for such purpose, as it allows to combine different quantitative indicators and perspectives. In our study we explored the combination of material circularity based- and life cycle based-indicators via the TOPSIS methodology. We focus on a specific product category, i.e. beer packaging, as representative of the FMCG, but our proposal of coupling material circularity indicators with LCA indicators via MCDA can be applied to other relevant sectors for CE, such as electronics, building, water systems, food waste (EC et al., 2015b). In principle, our proposal can be applied not only at the micro, but also meso and macro levels, provided that a set of relevant indicators are selected. It can be relevant in the context of the monitoring framework for the circular economy proposed at the European level (European Commission, 2018), which aims at measuring progress towards a circular economy by means of 10 indicators addressing four aspects of the CE, namely i) production and consumption, ii) waste management, iii) secondary raw materials and iv) competitiveness and innovation (Mayer et al., 2018). As outlined by Elia et al. (2017) focusing on one single dimension (or a limited set of dimensions as in our case) represents a limitation in the assessment of CE models, and thus this is a limitation of our study. We indeed focused our analysis to a selection of material circularity and LCA indicators, but our approach of coupling several indicators via MCDA can be extended to incorporate a broader spectrum of CE indicators (Pauliuk, 2018), also including economic value (Di Maio et al., 2017; Linder et al., 2017) or in the case of MCI, the so-called complementary risk and impact indicators included in the MCI project (EMF and Granta Design, 2015). Moreover, the possibility of adopting different MCDA methodologies than TOPSIS could be explored, as it is recommended to apply more than one MCDA method to ascertain the results (Balasubramaniam et al., 2007). However, Kalbar et al. (2015, 2012) demonstrated that if the decision problem is structured appropriately, via formulating scenarios depicting the real-life situations or stakeholder preferences, application of many of the MCDA methods will result in the same outcome.

Finally, MCDA is particularly suited to address different quantitative and qualitative sustainability aspects and our findings confirm the role of CE and the relevance of index towards the achievement of sustainable development goals (Cucchiella et al., 2017; Gaustad et al., 2018; Haupt et al., 2017). Thus we recommend extending the life cycle perspective to the economic and social dimensions, e.g. through the Life Cycle Sustainability Assessment (LCSA) framework (Halpenny and Manik, 2011). The development of combined circularity (and longevity) indicators via MCDA can be applied to other relevant sectors for CE, such as electronics, building, water systems, food waste (EC et al., 2015b). In principle, our proposal can be applied not only at the micro, but also meso and macro levels, provided that a set of relevant indicators are selected. It can be relevant in the context of the monitoring framework for the circular economy proposed at the European level (European Commission, 2018), which aims at measuring progress towards a circular economy by means of 10 indicators addressing four aspects of the CE, namely i) production and consumption, ii) waste management, iii) secondary raw materials and iv) competitiveness and innovation (Mayer et al., 2018). As outlined by Elia et al. (2017) focusing on one single dimension (or a limited set of dimensions as in our case) represents a limitation in the assessment of CE models, and thus this is a limitation of our study. We indeed focused our analysis to a selection of material circularity and LCA indicators, but our approach of coupling several indicators via MCDA can be extended to incorporate a broader spectrum of CE indicators (Pauliuk, 2018), also including economic value (Di Maio et al., 2017; Linder et al., 2017) or in the case of MCI, the so-called complementary risk and impact indicators included in the MCI project (EMF and Granta Design, 2015). Moreover, the possibility of adopting different MCDA methodologies than TOPSIS could be explored, as it is recommended to apply more than one MCDA method to ascertain the results (Balasubramaniam et al., 2007). However, Kalbar et al. (2015, 2012) demonstrated that if the decision problem is structured appropriately, via formulating scenarios depicting the real-life situations or stakeholder preferences, application of many of the MCDA methods will result in the same outcome.

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measures coupled with LCSA is also encouraged by Figge et al. (2018) as one of the most urgent research needs within CE metrics. The possibility of coupling different types of indicators is of particular relevance in view of the recent proposal submitted by the French National standardization body to the International Organization for Standardization to establish a new technical committee for the development of a management system related standard addressing the identification of metrics to be used by organizations to measure the progress made in the implementation of a CE project (AFNOR, 2018).

4. Conclusions

In the “closed loop” circular economy research model introduced by Babbitt et al. (2018) in their editorial to the recent Special Issue of this journal on Sustainable Resource Management and the Circular Economy, the urgency of continually testing the real-world implementation of theoretical circular economy tools has been stressed. Our study contributes to the debate on the selection of the most suited metrics for CE implementation at the product level and adoption of framework for assessing product circularity with such metrics. We investigated the possibility of coupling different types of indicators addressing CE strategies at the product level via MCDA and validated our proposal with two cases in the packaging sector. We compared four packaging alternatives for beer in the UK and Indian markets, respectively, by means of two types of indicators: materials circularity based (MCI and MRS) and life cycle based (CC, ARD, AC, PM, WC) and found that the ranking changes according to the indicator set. Such conflict can be solved by coupling the indicators via MCDA, which supports the integration of different perspectives. Therefore, we recommend the use of TOPSIS (or similar methods) to make sense of the complementary CE indicators currently available and we encourage researchers to further explore the application of the MCDA framework and life cycle based indicators (including the socio-economic dimension) to address CE trade-offs and rebound effects.

Acknowledgments

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References


