

Article

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

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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.

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... 1533). [15] finds that companies in the fast-moving consumer goods sector make limited use of performance indicators or quantitative CE assessments in their implementation of CE-related policies. Only a small fraction of investigated organizations presents a dedicated set of key performance indicators (KPIs) to their approach to CE. ...

... In 14 of those cases, LCA is used in combination with other existing methods. These combined methods are very diverse and include methods such as Material Flow Cost Accounting [46] or a Material Reutilization Score [15]. They are summarized in Table 6. ...

... Method [52] LCA, LCC, S-LCA [53] LCA, MFA, multi-objective optimization [54] LCA, LCC [55] LCA, LCC, S-LCA [45] LCA, Environmental Input-Output (EIO) [56] LCA, Recyclability Benefit Rate (RBR), Recycled Content Benefit Rate (RCBR) [57] LCA, MFA [58] LCA, MFA, Constructive Technology Assessment (CTA), input-output analysis, LCC, Cost-Benefit Analysis (CBA) [15] LCA, Material Reutilization Score (MRS), MCI [59] LCA, MFA, LCC, S-LCA [46] LCA, Material Flow Cost Accounting (MFCA) [42] LCA, E-factor [60] LCA, Net Present Value, Internal Rate of Return, questionnaire on stakeholder perception [61] LCA, Environmental Product Declaration ...

A Critical Review of Academic Approaches, Methods and Tools to Assess Circular Economy at the Micro Level

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● Erik Roos Lindgreen · ● Roberta Salomone · ● Tatiana Reyes

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... The authors proposed resolving trade-offs through multi-criteria decision analysis to enable coupling of the methods in which case circularity and environmental impact categories are weighted to reach a single score. The authors use TOPSIS method to identify the numerical distance from Positive Ideal Solution and Negative Ideal Solution, thus

enable MCI (benefit-type) and LCA results (cost-type) to be compared (Niero and Kalbar 2019). Lastly, Walker et al. (2018) compared several circularity indicators (including MCI) with carbon footprinting indicator. ... The need for normalization of MCI scores has been voiced previously (Niero and Kalbar 2019). In that instance, the authors normalize MCI scores to their Positive Ideal Solution and LCA categories to their Negative Ideal Solution and add another step of weighting to arrive at the single score. ... The graphical representation adopted in Walker et al. (2018) bears some resemblance to the approach proposed in our study. However, similarly to Niero and Kalbar (2019), normalization is made in reference to the most impactful scenario. ...

Towards sustainable energy materials : broadening life cycle assessment for emerging technology development and resource-effective choices

Thesis

Dec 2019

● Edis Glogic

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... According to Pauer et al. (2019), evaluations of food-packaging systems should include direct and indirect environmental effects, in addition to circularity assessments, yet without proposing a combined evaluation method. Niero and Kalbar (2019) already combined direct environmental effects (LCA results) of packaging and circularity metrics using multi-criteria decision analysis (MCDA). In context of this research, however, we argue that circularity parameters such as recycled content or recycling quotas may affect LCA results, thus violating the rules of using only independent attributes in MCDA (Belton and Stewart, 2003). ...

... In other impact categories, plastic packaging contributes 7% to 13% and glass packaging 29% to 31% to the overall result. Obviously, direct environmental impacts of glass packaging are associated with greater environmental impacts than plastic bottles, which is well in line with results of other LCA studies (Boesen et al., 2019; Humbert et al., 2009; Niero and Kalbar, 2019). Nonetheless, this is compensated for by its good emptiability. ...

... We conclude and agree with authors of similar previous studies that TOPSIS assists in overcoming the limitations inherent in LCA studies (Maxim, 2014; Niero and Kalbar, 2019), such as only considering environmental performance, while excluding assessments of other

sustainability dimensions (Zimek et al., 2019) or compliance with environmental regulations (Levy, 2017). The proposed sustainability assessment of food-packaging systems can solve multi-dimensional issues, particularly of conflicting sustainability goals. ...

Environmental and economic assessment of food-packaging systems with a focus on food waste. Case study on tomato ketchup

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... Rieckhof and Guenther (2018) integrate LCA and material flow cost accounting to assess resource productivity and both economic and environmental performance. Landi et al. (2018) complement LCA with cost-benefit analysis (CBA), whilst Niero and Kalbar (2019) combine LCA with the Material Reutilization Score and the MCI. Niero and Hauschild (2017) suggest a framework that combines LCA, the MCI and life cycle sustainability framework. ...

... Whilst the literature provides some comparison between circularity indicators with environmental impacts at the product level (Niero and Kalbar, 2019 ; Walker et al., 2018), similar comparative research at the meso (including sector) or macro-level was virtually non-existent (although Wiebe et al. (2019) modelled CE changes at the macro-level). In other words, several mass flow indicators are proposed or used at the meso and macro-levels, but there is little research (or knowledge) on the correlation with environmental impact. ...

Circularity for circularity's sake? Scoping review of assessment methods for environmental performance in the circular economy

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... The relative low number of indicators found (30) indicates that

research into indicators for CE at a micro level is currently underdeveloped. This could be a result of the faster development of indicators at regional, national or global levels, and limited work has been done at organizational or product level (Cayzer et al., 2017; Niero and Kalbar, 2019; Pauliuk, 2018). A significant increase in publications can be seen during the past four years, which may reflect an increased awareness of the need to measure and document CE in relation to products and organizations. ...

... A similar lifecycle approach is also applied in the Multi-Criteria Decision Analysis Combining Material Circularity Indicators and Lifecycle Based Indicators (MCDA-ML) (Niero and Kalbar, 2019), which is a framework that addresses multiple dimensions of product circularity by combining material circularity indicators like MCI and MRS with lifecycle based indicators from LCAs. By combining these two types of indicators, MCDA-ML enables a nuanced assessment of circular strategies. ...

A review of micro level indicators for a circular economy – moving away from the three dimensions of sustainability?

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... For example, Niero and Kalbar (2019) use Multi-Criteria Decision Analysis (MCDA) to reconcile multiple product-level circularity impact metrics. The authors apply two material circularity indicators (Cradle to Cradle Products Innovation Institute's Material Reutilization Score and the Ellen MacArthur Foundation's Material Circularity Indicator) plus four different lifecycle analysis measures (carbon footprint, particular matter, acidification, water consumption, and abiotic resource depletion) to eight different beer packaging options, in the UK and India. ...

... It was also noted that while there has been a plethora of plausible circularity indicators presented in scientific outlets (Saidani et al., 2019), there are few published empirical tests of these indicators, and especially few that employ the same test across more than one product or several variations of a similar product (c.f. Walker et al., 2018; Niero and Kalbar, 2019). The research team applied a specific circularity indicator, C, to 18 products from 18 different companies and Table 3 Estimates and C, Simplified C, and associated lifecycle analysis results. ...

Product-level inherent circularity and its relationship to environmental impact

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... One way of looking at CE is by understanding how materials enter, flow and eventually leave the economy (European Commission, 2018). Whenever a material is reinserted into the economy during its use/ consumption phase or its end-of-life phase, its flow is considered to have become circular instead of linear (Zore et al., 2018; Niero and Kalbar, 2019). ...

... The more a material is imbued with circularity, the more value it provides during its lifespan and the less pressure is put on nature for new resources (Pauliuk, 2018; Niero and Kalbar, 2019). Material such as steel have theoretically infinite circularity due to their recyclability characteristics, still, its full potential is yet to be achieved (Worldsteel Association, 2015a; Ellen McArthur Foundation, 2013). ...

Supply chain integration strategies and circularity in the European steel industry

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... Garza-Reyes et al. also considered the MCI to be the most complete assessment framework for micro-level circularity available in literature (Garza-Reyes et al., 2018). Different authors have selected the MCI to measure the circularity at micro-level in their analysis of the trade-off between material circularity and environmental efficiency (Lonca et al., 2018; Niero and Kalbar, 2019). ...

Measuring the performance of more circular complex product supply chains

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... Already a lot of indicators, methods and tools have been developed to measure circularity at the micro level (Di Maio and Rem, 2015;EMF, 2015;Linder et al., 2017;Saidani et al., 2017; Niero and Kalbar, 2019) . However, in none of these contributions linkages with macro indicators or a more policy-oriented application are explored. ...

Towards a more direct policy feedback in circular economy monitoring via a societal needs perspective

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... Despite the similar limitations of other aggregation methods including possibility of the correlations between criteria and uncertainty in obtaining the weights (Xu et al. 2015), it is highlighted in the literature that TOPSIS has an advantage of avoiding the rank-conflicting difficulties and this is very useful for making decisions when dealing with a complicated important assessment indicator which might be either decreasing or increasing (Hwang and Yoon 1981;Hsieh et al. 2006). Similarly, Niero and Kalbar (2019) found that employing TOPSIS resolves the conflict between the indicators. Wang (2015) also applied TOPSIS to tackle the subjectivity issue in choosing energy indicators. ...

Identifying Social Indicators for Sustainability Assessment of CCU Technologies: A Modified Multi-criteria Decision Making

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... To assess the degree of CE implementation in the construction sector, Nuñez-Cacho et al. (2018) proposed a set of indicators that have been validated by industrial and academic experts. Moreover, **Niero and Kalbar (2019)** aimed to link material circularity-based indicators to lifecycle-based indicators at the product level. Some of these indicators are more product-oriented and some are more lifecycle-oriented. ...

CEIMA: A framework for identifying critical interfaces between the Circular Economy and stakeholders in the lifecycle of infrastructure...

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... The principles of circular economy (CE) aim for zero waste at all stages of a product's lifecycle [1,2,3,4, 5]. This requires incorporating design elements that support reducing, reusing, recycling, and recovering to keep products, components and materials circulating in the value chain for as long as possible. ...

Metnod for determining the Circularity Score of ICT goods

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... Paving the path towards more sustainable and circular operational patterns within the road engineering industry and its satellite clusters, frameworks such as the Life Cycle Sustainability Assessment, Life Cycle Assessment, Life Cycle Cost Analysis, and Multi-Criteria Decision Analysis, seem to be gaining strength and establishing their influence on

decision-making processes in a steadily increasing rate. However, so far, during the implementation of these frameworks, individually or in parallel, a significant element for these assessments seems to be missing; the Circularity Assessment [58][59][60]. This study, thus, attempts to provide a stepping stone towards the merging of two assessments; Sustainability and Circularity. ...

Integrating Circularity in the Sustainability Assessment of Asphalt Mixtures

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... Wohner et al. combined LCA and life cycle costing (value added, VA) using multi-criteria decision analysis (TOPSIS) in order to identify the most sustainable packaging system for food products [13]. Niero et al. used a beer packaging case to demonstrate that pairing different types of indicators via MCDA (multi criteria decision analysis) may help with the selection of the best alternative [14]. Another study showed that the frequently used returnable packaging systems in the automotive industry presented a technique to reduce waste, costs, and transport damages, Sustainability 2020, 12, 7304 3 of 19 enabling just-in-time (JIT) deliveries [15]. ...

Fuzzy Approach for the Decision on Disposable or Returnable Packaging

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... Several researchers have combined different sustainability evaluation tools to affect a broader perspective, in line with the concept of circularity. For example, Niero and Kalbar proposed the combination of different circularity and LCA-based indicators to measure CE performance at macro, meso, and micro levels, via MCDA [73]. This indicated a novel approach to assessing circularity at a product level, drawing on CE and eco-efficiency perspectives. ...

A Paradigm Shift in Sustainability: from Lines to Circles

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... An organization must strategically adopt the principles of the CE in the value chain management, e.g. in operations, logistics, etc., including waste management and secondary raw materials re-entering into the economic cycle (Ritzén and Sandström, 2017; Karagouni, 2018). Based on this concept several researchers have proposed different business models, categories of CE indicators or approaches for measuring products' and business performance, along with implementation techniques of the CE and establishment of closed loops, in various industries or national economies contexts (Bakker et al., 2014; Dieterle et al., 2018; Niero and Kalbar, 2019; Moraga et al., 2019). ...

Circular economy. The Greek industry leaders' way towards a transformational shift

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... Several other indicators are based on the same framework and with other weighting formula or included factors -they attempt to assess the same three main parameters. For instance, the Cradle to Cradle certification proposed a Material Reutilization Score (MRS) (Niero and Kalbar, 2019) to assess both the Intrinsic Recyclability (IR) and the Recycled Content (RC), according to the $MRS = \frac{IR + RC}{3}$ formula. Park and Chertow (2014) introduced the Resource Potential Indicator (RPI) to measure the intrinsic value for reuse of a material, taking into account the state-of-the-art recycling technologies. ...

Circularity indicator for residential buildings: Addressing the gap between

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... Several tools exist in both the academic and the grey literature to assess the LoC on macro-, meso-and micro-levels (Niero and Kalbar, 2019; Saidani et al., 2019; Saidani et al., 2017). From an inventory of product circularity assessments, the 'Building Circularity Indicator' (BCI) of Verberne (2016) is considered as the most appropriate tool for this research since the BCI tool represents circularity with a quantitative score on both building and component levels. ...

Exploring the relationship between the level of circularity and the life cycle costs of a one-family house

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... Circularity strategies may be evaluated through the lens of LCA in product design, end-of-life waste management and economic sectors, but such strategies might not necessarily be the optimal ones for a more sustainable environment, as discussed in a recent forum on LCA and Circular Economy (Haupt and Zschokke, 2017). Recently, some methodological improvements have been suggested in order to make LCA-based approaches more suitable for application toward circular economy, such as adopting an interpretative approach in LCA called "Life Cycle Gap Analysis" (Dieterle et al., 2018), coupling the Life Cycle Sustainability Assessment (LCSA) framework with the principles and framework of the recently published British Standard BS 8001:2017 (Niero and Rivera, 2018), and integrating circularity indicators with LCA indicators using the Multi-Criteria Decision Analysis (MCDA) framework (Niero and Kalbar, 2019). Despite the growing relevance of the emerging Circular Economy concept, there has been little interest in

adopting this approach on a practical level by the mining industry (Lebre et al., 2017). ...

Life Cycle Assessment in the minerals industry: Current practice, harmonization efforts, and potential improvement through the integratio...

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How Multi-Criteria Decision Analysis (MCDA) is aiding Life Cycle Assessment (LCA) in results interpr...

October 2017 · Journal of Cleaner Production

 Guilherme Marcelo Zanghelini ·  Edivan Cherubini · Sebastião Roberto Soares

Life Cycle Assessment (LCA) is a robust methodology that assesses the environmental impacts of product systems. However, assessing its outcomes is not always easy. When decision-making must be carried out in such complex situations, Multi-Criteria Decision Analysis (MCDA) may be applied. In this paper, the way in which MCDA techniques are being applied within the LCA context to aid results ... [\[Show full abstract\]](#)

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