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Published in:
Proceedings of Italian LCA Network conference XI

Publication date:
2017

Document Version
Publisher's PDF, also known as Version of record

Citation (APA):
Niero, M. (2017). Which role for Life Cycle Thinking in the definition of meaningful indicators for the circular economy? In Proceedings of Italian LCA Network conference XI (pp. 11-19)

Which role for Life Cycle Thinking in the definition of meaningful indicators for the circular economy?

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Abstract

There is an urgent need to provide companies with guidance on how to measure the performance of their products and activities in the implementation of circular economy (CE) strategies. This paper aims to contribute to the discussion on the identification of the most suited metrics for CE at the micro level. We discuss the role of Life Cycle Thinking (LCT) in the development of meaningful circularity indicators at the product level taking into account the absolute perspective on CE. Our analysis is limited to the environmental aspect of sustainability with a focus on the climate change impact. We use a case study of an aluminium can to illustrate the challenges arising from the use of some of the available metrics either directly or indirectly based on LCT, i.e. the Material Circularity Indicator and the Materials Reutilization Score for the product and the Sectorial Decarbonization Approach at the corporate level.

List of abbreviations used

CA = Company Activity
CC = Climate Change
CI = Carbon Intensity
CE = Circular Economy
C2C = Cradle to Cradle®
GHG = Greenhouse Gases
LCA = Life Cycle Assessment
LCSA = Life Cycle Sustainability Assessment
LCT = Life Cycle Thinking
MCDA = Multi Criteria Decision Analysis
MCI = Material Circularity Indicator
MRS = Material Reutilization Score
PB = Planetary Boundaries
RC = Recycled Content
RR = Recycling Rate
SA = Sector Activity
SI = Sector Intensity
SBT = Science Based Target

1. Introduction

Most current industrial sectors are still organized according to a linear economy, i.e. a so-called take-make-waste system. The circular economy (CE) provides an alternative to such economic system, being an industrial system that is restorative or regenerative by intention and design (EMF, 2013). The CE has been proposed to address environmental issues by transforming waste into resources, and bridging production and consumption activities. The transition to a functioning CE regime requires a systemic multi-level change, including technological innovation, new business models, and stakeholder collaboration (Witjes and Lozano, 2016).

As highlighted in recents reviews (Ghisellini et al. 2016, Geissdorfer et al. 2017) the conceptual development of the CE traces back to different disciplines, visions and schools of thought, such as the Cradle to cradle design framework (McDonough and Braungart 2002) or the Performance Economy (Stahel 2016). Several authors have recently proposed alternative frameworks to implement CE strategies at different levels. Niero et al (2017) defined a framework combining Life Cycle Assessment (LCA) and the Cradle to Cradle® (C2C) certification program to identify which actions should be prioritized to achieve a continuous material loop for beverage packaging, both from an environmental and an economic point of view. Niero and Hauschild (2017) recommends to use the Life Cycle Sustainability Assessment (LCSA) framework to evaluate circular economy strategies in the beverage packaging sector, since it is the most comprehensive and still operational framework and best at preventing burden shifting between stakeholders in the value chain. Lieder and Rashid (2016) proposed a practical implementation strategy for a regenerative economy and natural environment, which emphasizes a combined view of three main aspects i.e. environment, resources and economic benefits and underlines that joint support of all stakeholders is necessary in order to successfully implement the CE concept at large scale. Ronnlund et al (2016) developed an eco-efficiency indicator framework based on LCA covering 10 important issues of product environmental sustainability, e.g. some key aspects for implementing a CE, such as material efficiency and reutilization of secondary raw materials.

Life Cycle Thinking (LCT), which allows to get reliable information about environmental, social and economic impacts of product systems in a life cycle perspective (UNEP, 2012), deserves a central role in all the abovementioned CE frameworks, but it is not enough. There is an urgent need to provide companies with guidance on how to measure the performance of their products in the implementation of CE strategies. Most attempts to define indicators for measuring circularity have so far addressed the macro (i.e. region, nation, sector) and meso levels (i.e. eco-industrial parks) and only a limited number of indicators is available at the product level scale (Linder et al, 2017).

Moreover, as discussed in Niero et al. (2016a), when moving from the product to the company level, the main gap to be filled is to define targets for implementing circularity strategies at the corporate level considering an absolute environonmental sustainability perspective. To be sustainable in absolute terms, industries should indeed benchmark their activities not just against their competitors and their own previous offerings, but also against the space which will be available to them in a sustainable world (Hauschild, 2015). The so-called Science Based Targets (SBT) refer to emission reduction targets set by companies to reduce their Greenhouse Gases (GHG) emissions in line with the level of decarbonization required to keep global temperature increase below 2°C compared to pre-industrial temperatures (Krabbe et al. 2015). The use of SBT is spreading among companies and several methods are available, either based on physical or monetary indicators.

The aim of this paper is to contribute to the discussion on the identification of the most suited metrics for CE at the micro level, i.e. products and company. We discuss the role of LCT in the development of meaningful circularity indicators at the product level taking into account the absolute perspective on CE. Our analysis is limited to the climate change impacts and we use a case study of a packaging for beer, i.e. aluminium can, to illustrate the challenges arising from the use of available metrics, both directly and indirectly based on LCT.

2. Materials and methods

2.1. Selection of metrics and criteria

Of all the product-level circularity indicators available (see Linder et al. 2017 for a review) two have been developed to be used within a company context, i.e. the Material Circularity Indicator (MCI) and the Material Reutilization Score (MRS).

The MCI was developed by the Ellen Mac Arthur Foundation and Granta (2015) in the context of the MCI Project aiming to find indicators to measure how well a product performs in the CE context. Several indices were developed, i.e. the main indicator MCI measuring how restorative the material flows of a product or company are, and complementary indicators allowing additional impacts and risks to be taken into account. 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) *recycled content* (*RC*); ii) *utility* during use stage; iii) destination after use, i.e. the *recycling rate* (*RR*) and iv) efficiency of recycling, i.e. the *yield* of the recycling process.

The MRS is the metric used to quantify material reutilization (MR), being one of the 5 criteria included in the C2C certification program (C2CPII, 2016). The MRS quantifies the recyclabilty potential of a product considering two variables: the *intrinsic recyclability* of the product, i.e the % of the product that can be recycled at least once after its initial use stage and the %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. Table 1 summarizes the criteria considered by such indicators to calculate the circularity of a product, as well as their formula.

Apart from the MCI and MRS, also LCA is recognized as a suitable tool to measure the environmental performances of products in a CE, although some adjustments are needed, e.g. to assess multiple life cycles in the case of aluminium products (Niero and Olsen, 2016). One challenge that needs to be overcome regards the quantification of the benefits from recycling, since the traditional 1:1 *substitution ratio of recycled to virgin materials* is questioned by some authors, e.g. Gala et al. (2015) who suggest to calculate such benefits considering the market-average mix of virgin and recycled materials.

Table 1: Main criteria to assess the circularity of a product with the Material Circularity Indicator (MCI) and Material Reutilization Score (MRS).

Metric	Formula	%RC	%RR	Intrinsic recyclability	Yield	Utility	Substitution potential
MCI	https://www.ellenmacarthurfoundation.org/programmes/insight/circularity-indicators.	X	X	N/A	X	X	N/A
MRS	(%product recyclable * 2 + %RC * 1) / 3	X	N/A	X	N/A	N/A	N/A

2.2. Case study: aluminium can

We considered the case of a 33cl aluminium can used to contain beer and calculated the MCI, MRS and the climate change impacts (CC, kg CO_{2eq}). We considered 8 scenarios, i.e two baseline scenarios (n.1,2 in Table 2), and six alternative scenarios (n.3-8 in Table 2), obtained varying the following criteria: %RC, %RR, %intrinsic recyclability, substitution ratio. For all scenarios the yield during recycling is kept constant, equal to 96.5%, considering pre-processing yield and remelting yield, which in the case of a closed loop recycling are equal to 99% and 97.5%, respectively (Niero and Olsen, 2016). The can under study is assumed to be representative of an industry-average product, therefore the utility is considered equal to 1.

Moreover, we applied a method that allows calculating SBT to align corporate GHG emissions with climate goals, i.e. the so-called Sectorial Decarbonization Approach (Krabbe et al. 2015). This method derives carbon intensity (CI) pathways for companies based on sectoral intensity (SI) pathways from existing mitigation scenarios. According to Krabbe et al. (2015), SI (year 2050) = 1.42 t CO_2 /t Al, SI (year 2030) = 1.54 t CO_2 /t Al and SI (baseline year 2015) = 1.61 t CO_2 /t Al. The parameters used to perform the calculations of the annual emissions target are summarized in Table 2. They refer to an illustrative case of a company producing aluminium cans, considering 3 options: constant (50%), increase (75%) and decrease (25%) of market share for two of the scenarios reported in Table 2, i.e scenario 1 and 3.

Table 2: Input parameters used to calculate the Material Circularity Indicators (MCI), Material Reutilization Score (MRS), Climate Change impacts (CC) and the absolute annual emissions target. RC= Recycled Content, RR=Recycling Rate, CI= Company Intensity, Substitution refers to the substitution ratio of recycled to virgin material.

Scenario → **Parameter↓**	**1- Baseline (1:1)**	**2- Baseline (0:25:1)**	**3- RC=100% (1:1)**	**4 RC=100% (0.25:1)**	**5- RR=100% (1:1)**	**6- RR=100% (0.25:1)**	**7- Intrinsic rec (1:1)**	**8- Intrinsic rec(0.25:1)**
RC [%]	50	50	100	100	50	50	50	50
RR [%]	50	50	50	50	100	100	50	50
Intrinsic recyclability[%]	96.8[a]	96.8[a]	96.8[a]	96.8[a]	96.8[a]	96.8[a]	100	100
Substitution[-]	1:1	0.25:1[b]	1:1	0.25:1 [b]	1:1	0.25:1 [b]	1:1	0.25:1 [b]
CI baseline (2015) [t CO_2eq/t Al]	8.29	-	6.14	-	-	-	-	-

[a] equal to the weight of the can minus the lacquer, according to Niero et al. (2016b)

[b] equal to 0.25:1, according to (Gala et al. 2015).

3. Results and discussion

3.1. Circularity metrics at the product level

The results of the calculation of MCI, MRS and CC for the 33cl aluminium can case are reported in Table 3.

Table 3: Material Circularity Indicators (MCI), Material Reutilization Score (MRS) and Climate Change impacts (CC) in the 8 scenarios considered.

Metric	**1- Baseline (1:1)**	**2- Baseline (0:25:1)**	**3- RC=100% (1:1)**	**4 RC=100% (0.25:1)**	**5- RR=100% (1:1)**	**6- RR=100% (0.25:1)**	**7- Intrinsic rec (1:1)**	**8- Intrinsic rec(0.25:1)**
MCI [-]	0.55	0.55	0.77	0.77	0.77	0.77	0.55	0.55
MRS [-]	81.2	81.2	97.9	97.9	81.2	81.2	83.3	83.3
CCa [kgCO2eq/hl]	35.0	42.0	25.9	32.9	26.7	40.7	40.2	N/A

[a] Niero et al. (2016b)

The same results are also reported in Figure 1 in relative terms, i.e. normalized to the highest score for MRS and MCI and presented as percentages. For those two indicators, the higher the score, the better the scenario is. Meanwhile for CC a higher value corresponds to a higher impact, therefore the scores are normalized against the highest score and inverted to be presented as 100% minus the normalized score. In this way the better solutions are those corresponding to a higher score and their ranking of the scenarios can be compared with the ranking obtained with the other two indicators. Some minor differences in the ranking patterns are observed between the three metrics, although the scenarios with 100%RC and 100%RR perform best for all metrics. For CC there is a distinction between the cases of 1:1 and 0.25 substitution ratio of secondary to primary, meanwhile MRS and MCI there is no distinction.

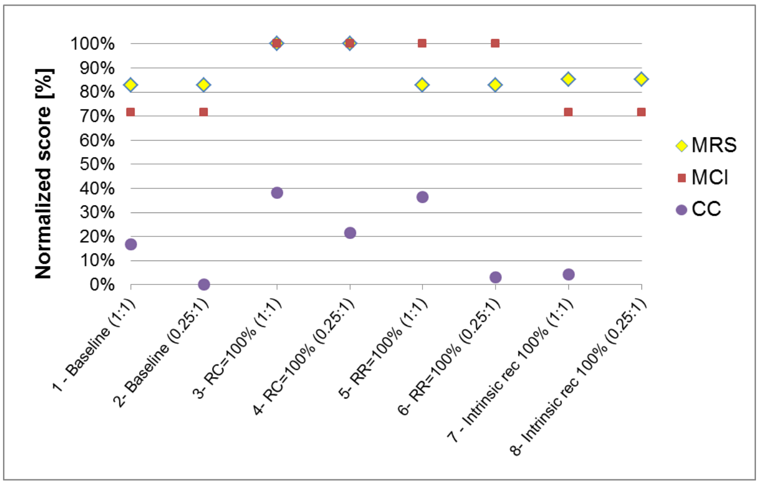

Figure 1: Normalized score (%) of the Material Reutilization Score (MRS), Material Circularity Indicator (MCI) and Climate Change impact (CC) for the scenarios listed in Tables 2 and 3.

3.2. Reduction targets at the corporate level

The outcome of the Carbon Intensity (CI) calculation for a company producing only 33cl aluminium cans, considering a baseline CI of 8.29 kg CO_{2eq} (corresponding to case 1 in Table 3) and lower baseline CI of 6.14 kg CO_{2eq} (corresponding to case 3 in Table 3) are reported in Figure 2. Three different options for their market share in year 2030 have been assumed, i.e. constant value of market share (CA=50%), increased (CA=75%) and decreased (CA=25%). The results in Figure 2 show that the variation required to be compliant with the SBT between baseline year (i.e. 2015) and 2030 is higher if the value of CI in the baseline year is higher, e.g. the difference of the CI in year 2015 and 2030 between case a (with initial CI of 8.29 t CO_2eq/t) and case b (with initial CI of 6.14 t CO_2eq/t) is of -31% and -28%, respectively. The influence of the market share is even higher than that of the initial CI: see case c, where a reduction of 48% is required (8.29 t CO_2eq/t vs 4.31 t CO_2eq/t). On the contrary, if a company reduces its market share from 50% to 25%, then it could increase its CI up to 22% and still be compliant with its SBT (according to the SDA method), see case e (8.29 t CO_2eq/t vs 10.10 t CO_2eq/t).

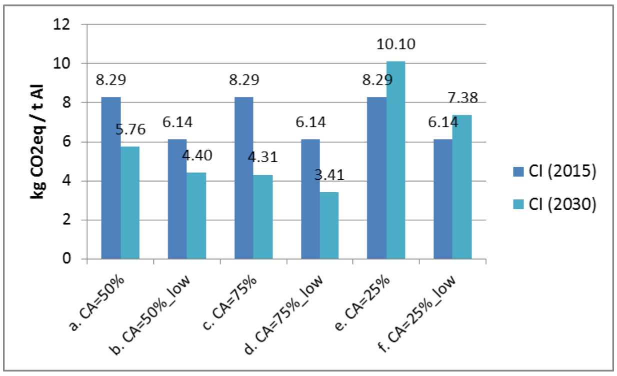

Figure 2: Carbon Intensity (CI) in year 2015 and year 2030 considering as baseline CI 8.29 kgCO$_{2eq}$ and a lower value of 6.14 kgCO$_{2eq}$ and 3 options for market share (50%, 25%, 75%).

3.3. On the features of meaningful indicators for CE

The results obtained from the aluminium can case provide some interesting perspectives on the use of different metrics to measure the circularity of a product and the definition of absolute target reductions for companies. Each metric only includes a selection of features: %RC and potential recyclability (MRS), %RC and %RR (MCI). However, the MCI does not distinguish between the case of 100%RC and 100%RR, meanwhile the MRS does not include the influence of %RR. Both MCI and MRS do not take into account the substitution ratio of recycled to virgin materials. Only the CC, calculated based on the LCA methodology is able to include all these relevant parameters, since it is the only metric based on LCT. However, even CC should not be used alone, since there may be trade-offs between impact categories associated with e.g. increased RC, as demonstrated by Niero et al. (2017) for the impact categories metal depletion and freshwater ecotoxicity.

Several authors recently advocated the use of circularity indicators based on economic value, such as the ratio of recirculated economic value to total product value proposed by Linder et al. (2017) or the Circular Economy Index defined by Di Maio and Rem (2016) as the ratio of the material value produced by the recycler by the intrinsic material value entering the recycling facility. However, the use of metrics based on economic value does not necessarily provide meaningful information, as shown in Figure 2 by the calculation on the target GHG emission reduction, where the relevance of the % market share appeared to be higher than the initial baseline carbon intensity. This suggests that calculations on absolute GHG reduction targets should not only rely on physical or monetary indicators, but rather take into account a broader perspective in terms of absolute environmental sustainability, e.g. in accordance to the Planetary Boundaries (PB) framework. The integration of the PB into LCA is currently under development (Ryberg et al. 2016).

Finally, the LCT should be applied consistently to both the economic and environmental dimension of the CE, in terms of scoping of the system, and this necessitates development of comprehensive CE indicators. However, in order to be meaningful such indicators should not only address the environmental and socio-economic impacts of circularity strategies, but also to include an integrated perspective on the two. Multi-Criteria Decision Analysis (MCDA) methodology is suited to address this challenge, since it provides an integration approach to aggregate results of different methods and to rank alternative scenarios (Halog et al. 2011).

4. Conclusions

The development of meaningful indicators for the CE should be based on LCT. At the product level, all different aspects related to product circularity should be investigated, such as %RC, %RR, intrinsic recyclability, yield during recycling, potential to substitute primary resources. Moreover, the potential environmental impacts quantified by means of LCA should also be included, as well as a quantification of the socio-economic implications. The open challenge is to find the balance between comprehensiveness and applicability, as well as how to relate such indicators to the absolute sustainability perspective.

5. Acknowledgments

The authors would like to thank the Carlsberg Foundation for funding the project "*Absolute Circular Economy" (ACE) toolkit to support companies in the implementation of Circular Economy strategies from an Absolute environmental sustainability perspective*".

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