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BENCHMARK OF CIRCULARITY INDICATORS AND LINKS WITH LCA

ENGLISH SUMMARY

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BENCHMARK OF CIRCULARITY INDICATORS AND LINKS WITH LCA

SCORE LCA is an association that has been created to financially support collaborative research on LCA and related topics. It aims to promote and organize cooperation between companies, institutional and scientists in order to support the evolution of LCA methods and its practical implementation at European and international level.

- ✓ This work has been supported by ADEME (Agence de l'Environnement et de la Maîtrise de l'Energie) www.ademe.fr
- ✓ The views and recommendations expressed in this publication are those of the authors and do not necessarily reflect, unless otherwise stated, the views of all members of SCORE LCA.
- ✓ The information and conclusions presented in this document were established on the basis of scientific and technical data and regulatory and normative framework in force at the date of the publication of documents.

1 Introduction

Motivation and stake of moving toward a circular economy for industry

The concept of circular economy (CE) calls for a more sustainable and reasoned management of resources throughout the life cycle of products and systems. Such an economic paradigm is characterized, on the technosphere side, by looping flows and by promoting maintenance, reconditioning and recycling operations, while being accompanied by service and take-back offers that make these practices operational. Circularity aims to maintain the high value and usefulness of products, materials and resources at all times, thus minimizing waste generation and environmental impact. In this line, a growing number of companies and local authorities is committed to engage in the transition of their business models towards "circular" models. On both sides, a need is emerging for medium- and long-term management of investments and material and energy flows at the level of territories and industrial organizations. Therefore, it became necessary to develop methodologies and tools based on relevant investment and flow management indicators for the variety of stakeholders concerned.

At the same time, many tools, methods, and indicators are currently available and can be activated to diagnose the environmental performance of a company's products, services, projects, and activities. In front of this multitude of tools, it is not straightforward for industrialists to identify the most relevant ones with regard to the objective and the timeframe of the project. Similarly, if we favour an analysis based on the principle of the circular economy, many indicators are available but are often limited to a diagnosis. As such, in order to promote projects that are favorable to the ecological transition and that create value for the company, it is necessary to mobilize indicators that will be used to monitor activities towards greater circularity and environmental preservation.

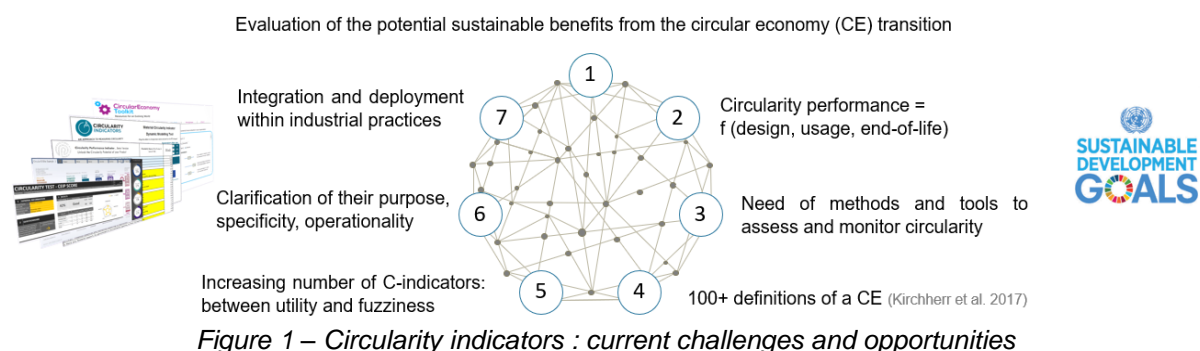
Emerging demand on circular economy assessment

As mentioned in the text of the SCORELCA call for projects NB 2020-03, more and more organizations want to achieve circular economy objectives and are taking steps in this direction. In order not only to monitor their progress but also to communicate their progress, these organisations need circularity indicators, as key performance indicators (KPIs), that enable them to achieve their objectives. The use of indicators seems *a fortiori* relevant for such a complex concept - multi-scale, multi-actor, advocating life cycle consideration and systemic thinking - as the circular economy. Indicators have the capacity to synthesize the complexity of our changing environments into a more easily understandable, manageable, and exploitable amount of information. More generally, such circularity indicators can be used for informational (e.g., benchmarking, decision support), improvement (identifying points of progress), managerial (leading change), communicative, formative, or educational purposes.

A common vision - shared by academics, industry, and political bodies (Ellen MacArthur Foundation, 2015; Geissdoerfer et al., 2017; Saidani et al., 2017) - has emerged on the need to measure the progress and impacts of this transition. Thus, many circularity indicators have been developed in recent years as tools and catalysts towards more circular practices, under the *sine qua non* condition that the actors involved in this transition can have access to and properly employ the indicators that are most appropriate for them, as illustrated in Figure 1. However, the progressive implementation, outside of any normative context, of these indicators has led to an heterogeneity of approaches to measure circularity (Saidani et al., 2019a). Although the notion of circular economy is increasingly discussed and recognized as contributing to the achievement of the Sustainable Development Goals, there is still no consensus on a stabilized definition of circular economy: 114 definitions of circular economy, transcribed into 17 categories, were notably identified by Kirchherr et al. (2017). This can be seen as one of the reasons for the vagueness and wide variety of indicators developed in relation to the circular economy, whether in terms of their scope of action, their primary objectives, or their preferred uses.

The aim of this project is both to provide clarity on this multitude of available indicators, as well as to help select a set of circularity indicators that are the most relevant, specific, and operational for an organization.

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Towards a sustainable circular economy: positioning and promising perspectives

Complementary to the SCORELCA project (2019) on "Material loops, product loops and LCA" (Study No. 2018-02), which resulted in recommendations for the assessment of the environmental performance of loops, this project aims to dive further into circularity assessment, and produce recommendations for circularity indicators that integrate the environmental aspect. These analyses and recommendations will be based on a structured analysis of existing indicators and may serve as a contribution to standardization at ISO/TC 323. In addition to producing measurements, these circularity indicators must also lead to useful and justified actions on the part of industrial players, through, e.g., transition management, improvement, or mitigation plans. Although circularity indicators seem to be a good help to accompany and guide these practitioners in taking into account the components of the circular economy, there is a notable gap between the (theoretical) indicators developed by academics and their (practical) use in industrial reality. The co-construction of these indicators is a way forward. In this spirit, the inventory and classification of circularity indicators can serve as a basis not only for testing and validating (or not) their proper understanding by designers, engineers, manufacturers, or project managers, but also for identifying the shortcomings of current indicators in order to consider their consolidation, combination and/or the construction of new indicators (Saidani et al., 2019b).

In practice, although a wide variety of indicators have been developed in recent years, it remains to be seen how widely they have been adopted and how mature they are in their use by industrial players, particularly in an integrated way with the design and development process. On the one hand, it seems that these circularity indicators - which can be considered as high-level heuristics or KPIs - and their associated tools are more rapidly deployable and easier to understand than certain environmental assessment methods and indicators such as life cycle assessment (LCA). On the other hand, to support sustainable decision-making, it remains to provide tangible proof that these indicators are correlated with an economic, environmental and/or societal "better". It is thus necessary to be able to validate whether this shift to more circular practices brings about a "better" outcome to the three pillars of sustainable development, for example, by comparing these intrinsic circularity indicators with certain indicators designed to gauge economic, environmental and/or social performance, thus assessing the consequential circularity of existing circularity loops and verifying (or not) the compatibility of the circular economy equation with the one of sustainable development.

2 Objectifs and content of the study

The main objective of this study is to provide SCORELCA members with operational, complete, and harmonized indicators to measure the circularity of their activity. The secondary objective of this study is to make the link with other methods, in particular LCA, in order to integrate these indicators into existing environmental assessment tools if possible. The study is structured in three parts: state of the art, detailed analysis, and recommendations (see Figure 2).

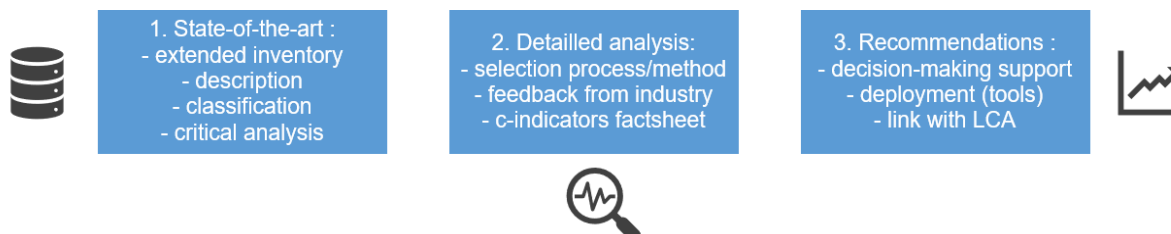


Figure 2 – Stepwise approach of the study

1. Performing a systemic state of the art: identification and analysis of indicators

- Specify the objectives that organizations wish to achieve with circularity indicators;
- Develop specifications for the circularity indicators to appropriately address the organisations' objectives..

2. In-depth analysis of 10 circularity indicators

- Propose a methodology for selecting the 10 indicators to be detailed;
- To develop a template for these indicators;
- To highlight the links between circularity indices, material flows, criticality indices, and LCA

3. Links with LCA and recommendations

- Produce recommendations on the use of appropriate, credible and operational circularity indicators;
- To provide recommendations on the implementation of the most relevant indicators in different contexts for their internal and external communication and to make them evolve in order to better meet the organizations' objectives.

3 Part 1: Literature review

The objective of this first part is to establish a robust state of the art concerning circularity indicators, of which there are a plethora. This state of the art is based on an exhaustive inventory of literature sources, and on an in-depth examination of a smaller number of indicators, in order to enable a selection and synthesis of 10 notable indicators.

3.1 Inventory and selection criteria

The literature review was based on the work carried out by Michaël Saidani in 2018 (Saidani, 2018; Saidani et al., 2019a), which identified 55 indicators of circularity. This work led to the creation of an online tool, the Circularity Indicators Advisor (CIA) (<http://circulareconomyindicators.com/>). The survey carried out as part of this study consisted of completing this work with the new publications published in the period 2019-2020. The bibliographical search thus carried out, which was completed at the end of 2020, made it possible to identify a total of 105 references corresponding to as many sets of circularity indicators. All these sources were referenced in an Excel spreadsheet, provided as one of the main deliverables of this study.

Academic papers dealing with c-indicators include, for example, the taxonomy of 55 sets of circularity indicators (Saidani et al., 2019a) or the critical review of 74 approaches, methods, and tools for assessing circularity performance at a micro scale (Roos Lindgreen et al., 2020). Other sources, non-academic but developed by business consulting groups (e.g., the Circular Transition Indicators) and environmental or institutional organizations (e.g., the 10 key indicators to drive the circular economy in France) were also considered.

Each source was characterized according to the initial criteria of the C-Indicators Advisor (CIA) tool (Saidani et al., 2020), which were completed in this study. The main criteria for characterizing the sources are:

- Level (scope) considered for circularity indicators:
 - Micro: material and/or product level

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- Meso: companies, industrial parks
- Macro: economic areas at the scale of regions, countries
- Type of circular economy loop:
 - Recycling
 - Reuse, remanufacturing
 - Life extension
- Perspective : (retrospective or prospective)
 - Potential (i.e., the potential for circularity of a product at the time of its design)
 - Effective (i.e., actual/actual circularity of a product)
- Performance as reflected in the circular economy indicator(s):
 - Intrinsic or flow (expressing a rate of resource recirculation, in %)
 - Consequential or impacts: environmental, social, economic impacts
- Type of source :
 - Academic
 - Company or consultant agency
 - Government or environmental organization

Figure 3 below shows the set of classification criteria used. This figure shows an increase in the categories of the circularity indicator taxonomy compared to (Saidani et al., 2019a), based on a review of existing literature, brainstorming, and feedback from SCORELCA members.

CE implementation level	CE loops	Circularity perspective	Circularity performance	Units
<ul style="list-style-type: none"> • Material / Product • Business / Activity • Region 	<ul style="list-style-type: none"> • Maintenance • Reuse/Reman • Recycling 	<ul style="list-style-type: none"> • Effective (retrospective) • Potential (prospective) 	<ul style="list-style-type: none"> • Impacts (effects) • Intrinsic (flow) 	<ul style="list-style-type: none"> • Quantitative • Qualitative • %, \$, CO2
Dimension	Usage (purpose)	Source (developers)	Transversality	Format (accessibility)
<ul style="list-style-type: none"> • Multi-score • Single score 	<ul style="list-style-type: none"> • Information • Decision-making • Communication • Education 	<ul style="list-style-type: none"> • Academic • Company • Organization (env., pol.) 	<ul style="list-style-type: none"> • Generic • Sector specific 	<ul style="list-style-type: none"> • Web-based • Excel-based • Formulas to compute
CE sphere	Life cycle stages	Use case	Popularity	Transparency
<ul style="list-style-type: none"> • Technosphere • Biosphere 	<ul style="list-style-type: none"> • Design • Manufacturing • Use • End-of-life 	<ul style="list-style-type: none"> • Yes • No • Link 	<ul style="list-style-type: none"> • Acknowledged • Intermediary • Marginal 	<ul style="list-style-type: none"> • Formulas available • Black box

Figure 3 – Set of classification criteria used for the analysis of the identified sets of indicators (illustrated, the ten initial criteria in blue (Saidani et al., 2019a), the five new criteria in gold)

3.2 Analysis and classification of circularity indicators

These criteria are used to categorize these 105 sets of circularity indicators:

- Distribution of sources: academic/consultant/government (Figure 4)
- Distribution by sectoral cross-section of the application: generic/specific (Figure 5)
- Distribution by circularity perspective: potential/actual (Figure 6)
- Breakdown by type of circular economy loop: recycling/repair/reuse (Figure 7)
- Breakdown by type of performance: intrinsic, consequential (Figure 8)



Figure 4 – Distribution of academic/consultant/government sources

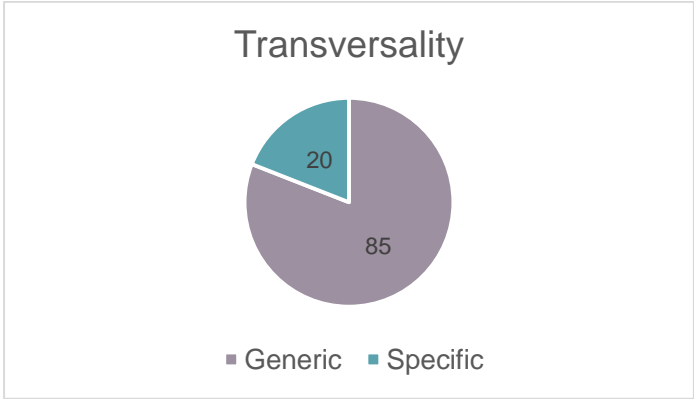


Figure 5 – Breakdown by cross-cutting application (generic or sector-specific)

N.B.: Among the 20 sets of industry-specific c-indicators, the building and construction (and deconstruction) sector is the most advanced in terms of sector-specific indicators.

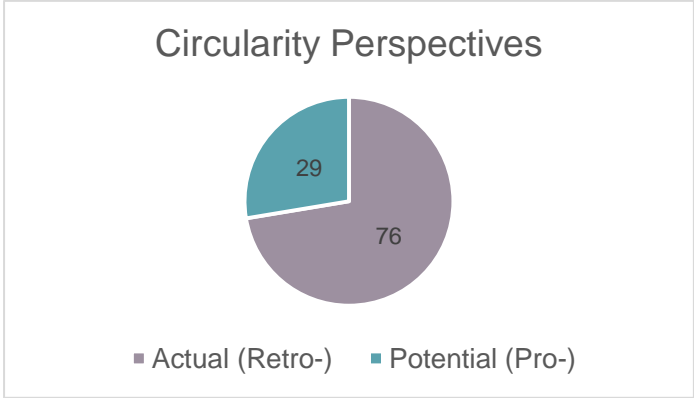


Figure 6 – Breakdown by circularity perspective (potential or actual circularity)

N.B.: Potential circularity indicators are particularly developed at a micro level, to be deployed when designing new products to assess their circularity potential.

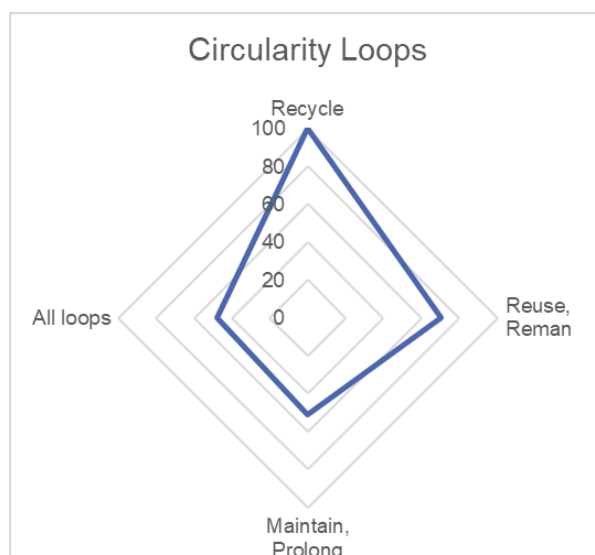


Figure 7 – Breakdown (number of c-indicators) by circular economy loops: recycling, repair, reuse, etc.

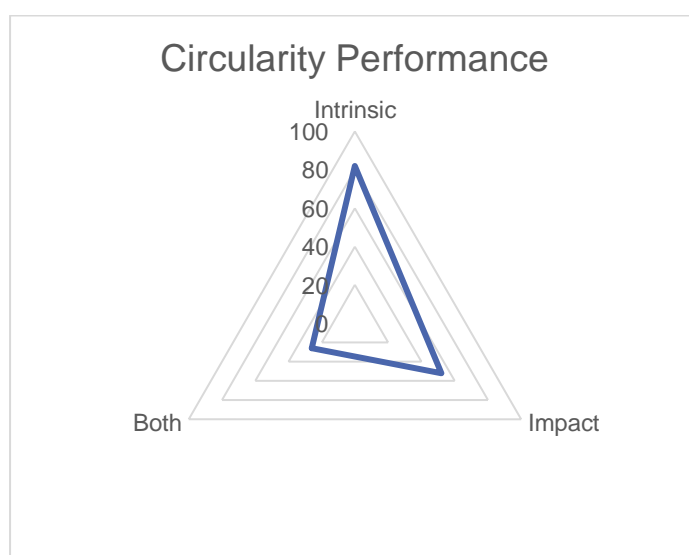


Figure 8 – Breakdown by type of performance: intrinsic (flow) vs. consequential (impact)

N.B.: Indicator sets covering both intrinsic and consequential circularity are mainly found at a macro scale (region, country).

3.3 Intermediate conclusion on the state of the art and reflection

Following this update of the circularity indicators census and statistical study, we can see the following trends: continuous growth since 2010, relatively homogeneous distribution on the three micro/meso/macro scales, indicators mainly developed by academics/university researchers (what about their applicability and practicability questioned in the following parts), cross-cutting indicators for the most part but a recent trend towards specification (e.g., the evolution of the Ellen MacArthur Foundation's Material Circularity Indicator for the building sector), recycling is the most considered/quantified circular economy loop, links between inherent circularity and circularity are more important than others. e.g. evolution of the Ellen MacArthur Foundation's Material Circularity Indicator for the building sector), recycling is the most considered/quantified circular economy loop, links between inherent (or intrinsic) circularity and environmental/economic/social consequence are not systematic.

Other aspects to be explored, some of which were mentioned and questioned during the SCORELCA 2021 annual feedback seminar, include: the distribution of indicators and their ability to cover both the technosphere and the biosphere so as to reflect the issues of each sphere; circularity indicators that can substitute for LCA (validation study through correlation); indicators for companies without expertise in eco-design or circular economy, i.e. indicators that do not require large internal resources, but that allow for progress in the right direction; circularity indicators more specifically for the services sector (to

highlight potentially hidden material flows). i.e., indicators that do not require a significant amount of internal resources, but that allow progress to be made in the right direction; circularity indicators more specifically for the service sector (to highlight potentially hidden material flows). Several of these unexplored aspects in an advanced or synthetic way, such as the link between circularity and life cycle analysis, are discussed and deepened in the following sections.

4 Part 2: In-depth analysis of 10+ c-indicators

Following the state of the art that enabled the inventory of published methods and indicators, and which showed the great diversity and heterogeneity of approaches, this second part consists of carrying out an in-depth analysis of about ten ad hoc and complementary indicators from among all those identified. To do this, the following tasks must be carried out sequentially:

- Develop a method for selecting these ten or so c-indicators and make the selection;
- Design a factsheet according to the main criteria to be analyzed;
- Complete the analysis according to each of the key criteria.

4.1 Selection process

We adopted an empirical and pragmatic method for the selection of the ten or so c-indicators on which to conduct a detailed analysis.

The first sorting criterion adopted is the type of method: among the 105 "sets of indicators", some methods are prescriptive (i.e., they give recommendations or guidelines, for the design of products or for the conduct of a company's circular economy strategy), others are indicators (i.e., calculation methods for measurement). For this study, only the measurement indicators are retained. The second sorting criterion is the transparency (i.e. formula for calculating the available indicator) of the method (or indicator), which is similar to the criterion of operationality. Once these initial sorting operations had been carried out, we sorted them into categories:

- On the one hand, the expectations (needs) of the industrial members of SCORELCA:
 - Need for sectoral indicators (specific to the industrial sector);
 - Need for micro indicators (at product or project level) and meso indicators (for reporting and steering at company level)
- On the other hand, the objective characteristics distinguishing the indicators, such as:
 - Indicators of recycling/material recovery ;
 - Indicators of product reuse;
 - Indicators on the circularity of materials/resources on a territorial scale;
 - Indicators on energy ;
 - Economic indicators ;
 - Social indicators ;
 - Design indicators (for circularity) ;
 - Aggregate indicator(s) ("score" of circularity).

The final choice of an indicator from the corresponding set (for example, which recycling indicator to choose from among all the recycling indicators), judged to be the "best" indicator, is ultimately based on Michaël Saidani's expertise, and confronted with a discussion and validation with the industrialists and SCORELCA partners who have followed this project. Finally, the last criterion, allowing the selection of indicators to be "completed", is that of the completeness of the set of indicators with regard to the various issues of the circular economy. The synopsis illustrating the selection method is shown in Figure 9.

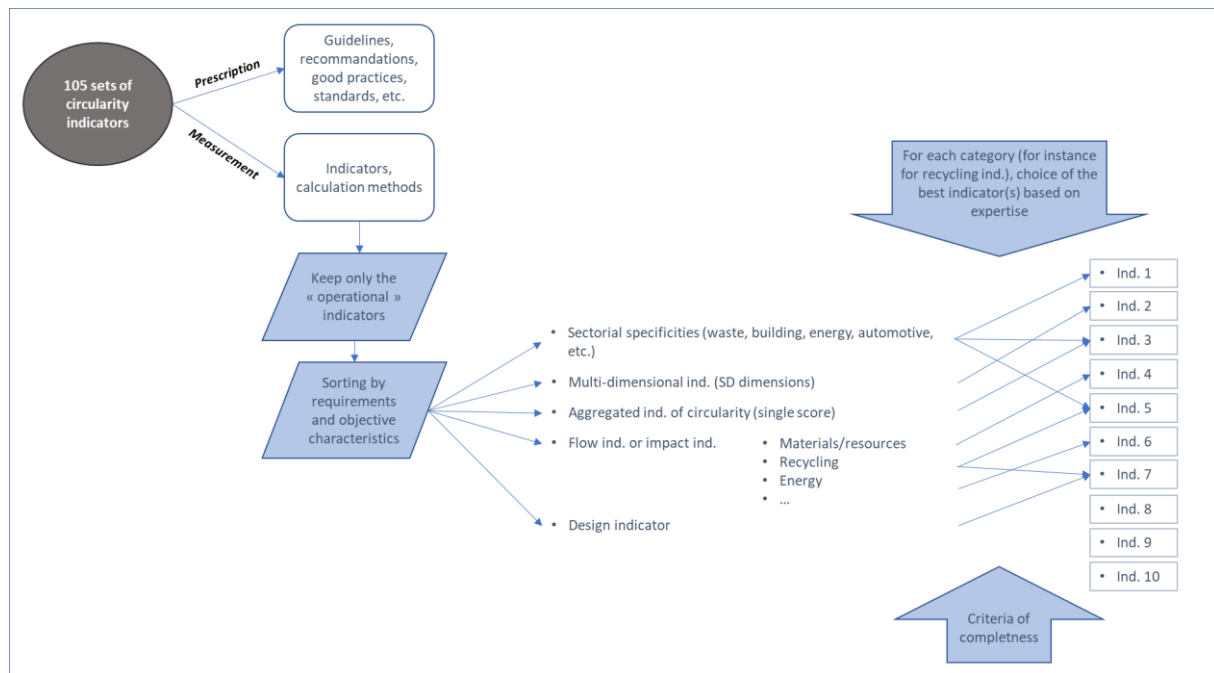


Figure 9 – Overview of the method for selecting the 10 indicators

4.2 List of the c-indicators selected

Following the process described in the previous subsection (selection method), a shortlist of indicators ranked according to the stated criteria is proposed below.

Two global evaluation indicators at the company level: Circulytics and CTI

- *Circulytics* (Ellen MacArthur Foundation tool): A new tool that reveals the extent to which a company has achieved circularity across its entire operations using a comprehensive set of indicators. It measures circularity in two main ways: enablers (what companies do for circular economy) and outcomes (Impact of the circularity action on inputs, used materials, energy, product reparability)
- *Circular Transition Indicators* (CTI): The CTI is the first self-assessment framework and online tool to measure circular business performance. This module calculates to what extent the organization is capable of guaranteeing material flows that loop back into the value chain after a product's technical lifetime. It defines an organization's circularity performance as the average between % circular inflow and % circular outflow.

Two indicators for assessing circularity at material and product levels: MCI and PCI

- *Material Circularity Indicator* (MCI): The MCI, developed by the Ellen MacArthur Foundation, combines aspects of lifetime and intensity of use with the proportion of recycled material and the share of materials in a product that can be recycled in a single indicator, applicable at the product or company level. It considers material rates of recycling and reuse, measures how restorative flows are maximized and linear flows are minimized, and also the length and intensity of the product's use.
- *Product Circularity Indicator* (PCI): The PCI is a new aggregated indicator at a product level, developed as an augmented version of the MCI.

One product design indicator (potential circularity): CCET (and two alternatives: CEIP, CPI)

- *Concept Circularity Evaluation Tool* (CCET): The CCET aims to support the evaluation of alternative product concepts in terms of their circularity potential in the early stages of product design and development. The CCET was iteratively developed based on an extensive literature

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review of the success criteria for tool development, guidelines, and existing tools for circular product design and development and strong collaboration with manufacturing companies.

- *Circular Economy Indicator Prototype* (CEIP): Using a points-based questionnaire (15 questions), the CEIP is initially intended to be used by manufacturing and/or retail companies of tangible goods with access to bills of materials. They would use the CEIP to measure and evaluate the performance of their products.
- Through a guided questionnaire of twenty attributes (ATT#) desired for a circular economy, that are based on and grouped within the four building blocks (BB#) of circular economy defined by Ellen MacArthur Foundation, the *Circularity Potential Indicator* (CPI) aims at evaluating the circularity potential of industrial products (during design, re-design or benchmarking phases) as well as providing keys for improvement and monitoring the circularity of products and businesses practices.

Two indicators of reuse/recycling and extension of the lifespan of products from a resource circularity perspective: RPI and CLI

- The *Reuse Potential Indicator* (RPI) indicates how much one material is “resource-like” rather than “waste-like” according to the currently available technologies. The proposed reuse potential indicator quantifies technical reusability. The tool specifies a continuum of how resource-like or waste-like materials are.
- *Circularity & Longevity Indicators* (CLI) combine two approaches - frequency (circularity) and duration of use (longevity) of products - to determine resource efficiency.

One set of 3 MFA-type material flow indicators: *End-of-Life Recycling Rates* (EoL-RRs)

- *End-of-Life Recycling Rate* (EoL-RR): performance of functional recycling, considering just pure materials
- *Recycled Content* (RC): fraction of secondary inputs in the total input of material production
- *Old Scrap Ratio* (OSR): fraction of old scrap in the recycling flow

One c-indicator of energy flow: CI

- *Circularity Index* (CI) formula :
 - $\text{Circularity Index (CI)} = \alpha\beta$, maximum value = 1
 - α = recovered end-of-life (EoL) material / total material demand
 - $\beta = 1 - \text{energy required to recover material} / \text{energy required for primary production}$

One set of indicators for circularity at the scale of a territory: RMFCE

- *Regional Material Flow tools for the Circular Economy* (RMFCE)

Two environmental impact indicators (in link with LCA): RBR and RCBR

- *Recycle Benefit Rate* (RBR) and *Recycled Content Benefit Rate* (RCBR): Recyclability Benefit Rate and the Recycled Content Benefit Rate indicators express the potential environmental benefits from recycling compared to disposal (e.g., incineration), taking into account life cycle thinking.

Socio-economic impact indicator(s) (in link with LCC and SLCA): SEI-EoL, TCR and TCO

- *Socio-economic Indicator for EoL Strategies for Bio-based Products* (SEI-EoL): The socio-economic aspects of EoL alternatives associated with bio-based products have been neglected. This paper contributes to filling this gap by proposing a new socio-economic indicator for EoL (SEI-EoL), calculating the values of the 25 socio-economic criteria including: 5 criteria (each) related to workers, consumers, general society, local community, value chain actors.
- Total Circular Revenue (TCR), Total Cost of Ownership (TCO).

In order to keep the maximum number of 10 factsheets, the selected circularity indicators are grouped by "category" (i.e., related indicators are summarised within the same sheet, see Figure 10):

Categories	Indicators	Acronyms	Tools
Factsheet 1: Circularity performance at the company level (corporate reporting)	Circulytics	Circulytics	Web-based
	Circular Transition Indicators	CTI	Web-based
Factsheet 2: Circularity at the material level	Material Circularity Indicator	MCI	Excel
Factsheet 3: Circularity at the product level	Product Circularity Indicator	PCI	Excel
Factsheet 4: Circularity performance of design alternatives	Concept Circularity Evaluation Tool	CCET	Excel
Factsheet 5: Reuse and life extension	Reuse Potential Indicator Circularity and Longevity Indicators	RPI CLI	Formulas
Factsheet 6: Material flow (MFA-like)	End-of-Life Recycling Rate Recycled Content Old Scrap Ratio	EoL-RR RC OSR	Formulas
Factsheet 7: Energy flow	Circularity Index	CI	Formulas
	Circularity of Material Quality	Qc	Formulas
Factsheet 8: Circularity at a territorial level	Regional Material Flow tools for the Circular Economy	RMFCE	Formulas Excel template
Factsheet 9: Environmental impact of circularity	Recycle Benefit Rate	RBR	Formulas
	Recycled Content Benefit Rate	RCBR	
Factsheet 10: Socio-economic impact	Socio-economic Indicator for EoL	SEI-EoL	Formulas
	Strategies for Bio-based Products	TCR	
	Total Circular Revenue	TCO	
	Total Cost of Ownership		

Figure 10 – 10 factsheets associated with the selected circularity indicators

4.3 Newly designed factsheet for the selected c-indicators

The selected indicators are transposed into self-supporting indicator sheets. Inspired by existing sheets published in the literature, the new sheets have been developed (completed and illustrated) with a view to teaching. These original factsheets are based on the classification criteria set out in Part 1.

Hereafter is the new factsheet model illustrated through the MCI, which is currently one of the most used circularity indicators, although it has some limitations. The other factsheets are available in the full report, and in the native format (PPT) for SCORELCA members, or on-demand.

Material Circularity Indicator (MCI)

Source: Ellen MacArthur foundation and Granta Design, 2015

Presentation

The Material Circularity Indicator (MCI) for a product measures the extent to which linear flow has been minimized and restorative flow maximized for its component materials, and how long and intensively it is used compared to a similar industry-average product.

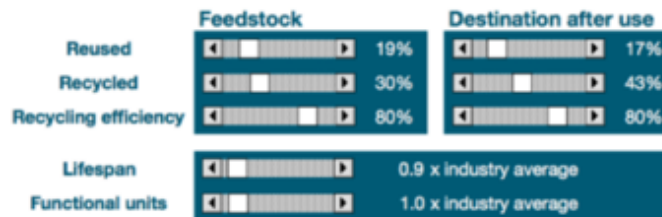
The MCI measures the level of circularity in the range 0 to 1, where higher values indicate a higher circularity.

The MCI has two main objectives:

- Compare different solutions of materials / products
- To know on which natural resources we depend and in what extent



MCI = 0.50



Overview of the interface and result

Expression et calculation

Total mass of virgin material

- ❖ Fraction of feedstock derived from recycled resources
- ❖ Fraction of feedstock derived from reused resources

Total mass of unrecoverable waste

- ❖ Fraction of product collected for recycling (at EOL)
- ❖ Fraction of product going into component reuse
- ❖ Amount of waste going to landfill or energy recovery
- ❖ Efficiency of the recycling process at products EOL
- ❖ Quantity of waste generated in the recycling process
- ❖ Waste generated to produce recycled content
- ❖ Efficiency of the recycling process for recycled content

$$MCI = 1 - \left(\frac{V + W}{2M + \frac{Wf - Wc}{2}} \right) 0.9X$$

Utility

- ❖ Product's and average industry's product lifetime
- ❖ Product's and average industry's intensity of use

General expression (automatic calculation following parameters to be filled)

The indicator is calculated thanks to an Excel table, available on free download:

<https://www.ellenmacarthurfoundation.org/resources/apply/material-circularity-indicator>



MCI calculation

Calculation parameters to be filled

	Feedstock	Destination after use
% Reused	Reused content rate	Reusable content rate
% Recycled	Recycled content rate	Recyclable content rate
Recycling efficiency	Loss rate during recycling	Loss rate during end of life recycling
Lifespan	Lifespan compared to industry average	Fill one of these two parameters
Functional units	Number of units used compared to industry average	

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Material Circularity Indicator (MCI)

Data input

A detailed bill of materials for the product is needed to compute the MCI, and more specifically:

- **Input in the production process:** How much input is coming from virgin and recycled materials and reused components?
- **Utility during use phase:** How long and intensely is the product used compared to an industry average product of similar type? This takes into account increased durability of products, but also repair / maintenance and shared consumption business models.
- **Destination after use:** How much material goes into landfill (or energy recovery), how much is collected for recycling, which components are collected for reuse?
- **Efficiency of recycling:** How efficient are the recycling processes used to produce recycled input and to recycle material after use?



Material flows taken into account in MCI's scope

Purpose of the indicator

Circularity perspective	Use (destination)	Transversality of the application	Performance evaluated
<ul style="list-style-type: none"> • Actual (retrospective) • Potential (prospective) 	<ul style="list-style-type: none"> • Information • Decision making • Communication • Education 	<ul style="list-style-type: none"> • Generic • Sector specific 	<ul style="list-style-type: none"> • Impacts (effects) • Intrinsic (flows)

Perimeter of circular economy covered

Implementation level	Size of the loop	Life cycle stages	Sphere of circular economy concerned
<ul style="list-style-type: none"> • Material / product • Organisation / activity • Territory 	<ul style="list-style-type: none"> • Maintain • Reuse / remanufactured • Recycle 	<ul style="list-style-type: none"> • Design • Production • Use • End of life 	<ul style="list-style-type: none"> • Technosphere • Biosphere • Both

Forecasting

The MCI is part of Circulytics, which provides a single score on a company level to describe a company's circularity. The co.project group is expanded the MCI methodology to include biological materials and addressed some of the challenges associated with combinations of biological and technical materials. The group is also addressing some of the risk-based complementary metrics for biological materials.

Crédits: CentraleSupélec & EVEA pour ScoreLCA – 2021

5 Partie 3: Links with Life Cycle Assessment (LCA)

In this third part, it is appropriate to illustrate the different possible synergies and/or conflicts (trade-offs) between LCA and circularity indicators in a practical way (with concrete examples) for SCORELCA members, as schematically illustrated in the two-dimensional graph in Figure 11. While we adopt the assumption that the circular economy remains (or should remain) a means to achieve the environmental, societal, and economic objectives of sustainable development, it would be of particular interest to see when circularity does and does not work towards sustainable development, and which parameters (in the loops) are critical. We can imagine three possible avenues to explore the links between LCA and circularity indicators:

- i. LCA output data (flows/midpoints/endpoints) are used as input data for the calculation of circularity indicators;
- ii. Circularity indicator(s) are integrated into the LCA output as a flow/midpoint/endpoint indicator (Saidani et al., 2019c);
- iii. LCA is used to verify the appropriateness of a set of circularity indicators (to be validated on known products, to save time compared to performing an LCA).

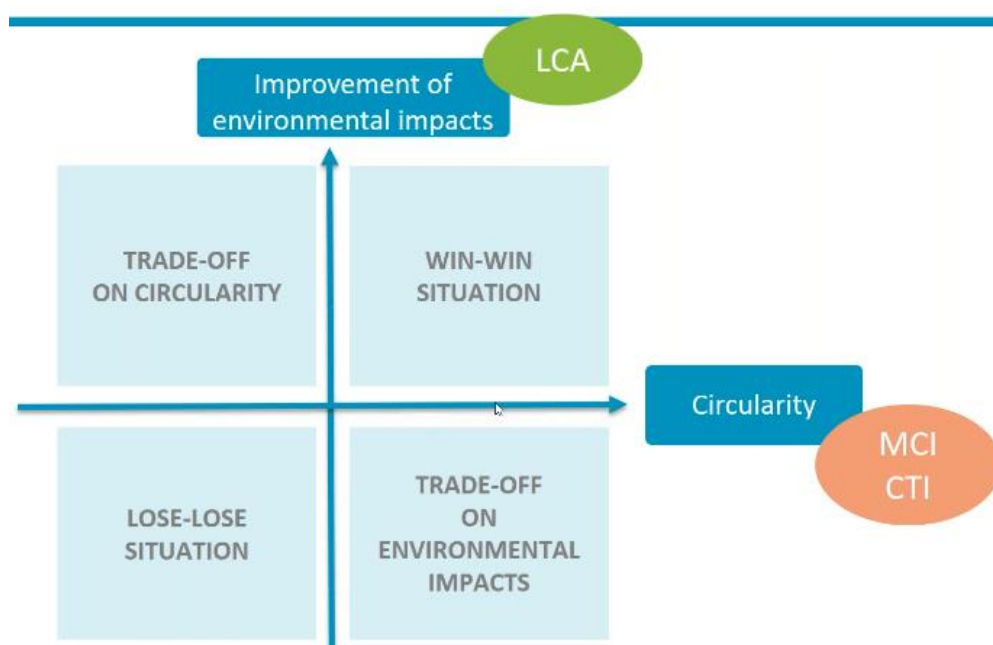


Figure 11 – Potential trade-offs between circularity and LCA. Source : Saunier, 2019. Webinar ACLCA

5.1 General remarks

On the one hand, CE focuses on maintaining (preserving and increasing) resource values for the economy. In doing that, CE considers also different levels of application: at the macro level, it focuses on material exchanges between the economy and the environment, and also internationally; at the structural or meso level, the emphasis is on material flows in industrial systems, distinguishing not only categories of materials but also sectors and industrial branches; at the micro or business level, it focuses on firms and their products. CE strategies often assume that it is always good to keep individual resources within the economy, either in use for as long as possible, or through cycling loops in technical or biological cycles (Pena et al., 2021).

On the other hand, LCA focuses mainly on product level and on all the impacts associated to the product life cycle, i.e. not only on the impacts related to the use of materials and resources but on all those impacts that can be relevant for a product category. LCA does not advocate for any specific strategy but simply provides an assessment framework to understand the environmental, social, and economic implications of different options to deliver a function or service. In this way, LCA and its related approaches may serve as the science-based methodology to assess the benefits or otherwise of specific CE strategies, and also the occasions where keeping the resources within the economy for longer may

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actually be counter-productive (e.g., due to the costs of removing toxic substances contaminating such resources) (Pena et al., 2021).

In all, the advantages of combining circular economy indicators with life cycle assessment include: identifying environmental trade-offs of circularity choices, broaden environmental analysis with LCA. However, in some cases, circular economy principles (or the application of circular economy strategies) and life cycle assessment results can have opposing views. Circular economy encourages recycling (no questions asked), while according to life cycle assessment, energy recovery is sometimes more beneficial. Additionally, LCA does not yet have all the answers when dealing with circular economy projects. For example, addressing the dissipative losses of raw materials are hardly taken into account by standard resource depletion indicators. Also, downcycling and upcycling are not straightforward to evaluate (Quantis, 2017). Finally, current research gaps include joint representation methods and how results are affected by methodological differences and limitations (e.g., the end-of-life allocation approach (cut-off, system expansion, hybrid approach), consequential vs. attributional approach (rebound effects on other actors and parts of the system), or the evaluation of secondary material quality loss).

In broad terms, it can be highlighted that (Pena et al., 2021):

- CE prioritizes the continued use of resources. This implies maintaining the highest level of utility of materials through recycling, either within the economy, typically through a network of industrial sectors, or in natural ecosystem processes, and may involve extending the lifetime of products to minimize the need for wasteful recycling activities.
- Methodologies and frameworks for the CE and the circularity assessment indicators are in development and aim mainly at augmenting the perceived value by increasing the utility value of resources within the economy.
- LCA can be used to measure and assess the environmental and social performance of a defined system in a circular economy, to ensure optimal decision-making.
- LCA is a well-established and standardized methodology adopted by industry worldwide, which allows characterizing the environmental performance of product systems, not only in relation to the impact associated to resource use, but to the whole range of impact categories relevant through the life cycle of the product.

In this line, the Life Cycle Initiative encourages LCA professionals to address the technical and scientific shortcomings involved in the assessment of CE projects, notably (Pena et al., 2021):

- Consistent accounting for changes in stocks of resources that respect mass balance principles;
- Consistent modelling of open recycling loops;
- The inclusion of all relevant resources and impacts, i.e., a full environmental, social and economy-wide (LCSA) perspective;
- Transparency of assumptions, reliability of data, and critical interpretation of results and trade-offs between a globally agreed number of impact categories.

In particular, it is important to recall here that seeking to maximize the performance or score/rate of circularity is not always the best option in terms of the costs and energy to be deployed (e.g., related to reverse logistics to collect all products, processing of certain materials). Indeed, achieving 100% circularity is often incompatible with the current industrial economic reality, end-of-life channels, and available technologies. In this sense, circularity performance should be used and optimized (as a cursor to be adjusted) as a lever to guarantee economic and environmental benefits. In practice, these trade-offs between economic, environmental, and circularity performance should be considered and optimized simultaneously. For example, a mathematical optimization model (Saidani et al., 2019d) has been proposed to find the circularity performance(s), maximizing the profile and minimizing the carbon footprint (see the Pareto frontier of 'circular green profit' in Figure 12).

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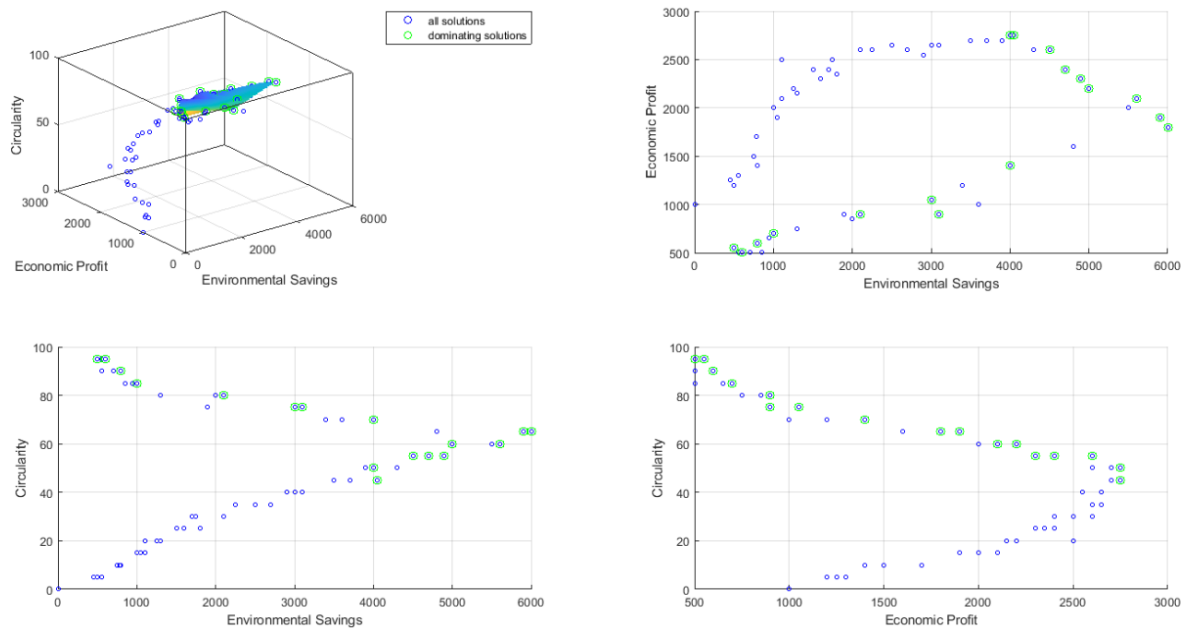


Figure 12 – Illustrations of the relationships and trade-offs between circularity, economic and environmental performance to be optimised (Saidani et al., 2019d)

5.2 Case studies 1 & 2: Comparison LCA / CE (Saunier, 19 ; Lonca et. al., 18)

To bring new insights on the question “Do circularity indicators and LCA provide the same results in the assessment of circular strategies?”, the CIRAIG (Polytechnique Montreal) compared circularity and life cycle assessment indicators for circular economy strategies on two industrial case studies: (i) increasing circularity for a plastic product company (case study #1), (ii) end-of-life strategies for used tires (case study #2). A third case study (Saidani et al., 2021) is available in the full report.

The objective for case study #1 is to assess the environmental relevance of initiatives and strategies to improve the circularity of a plastic product company: proposal of circularity strategies and scenarios to improve the score of circularity (MCI and CTI), organizational life cycle assessment and circularity assessment to better understand the link between maximizing circularity and minimizing life cycle impacts.

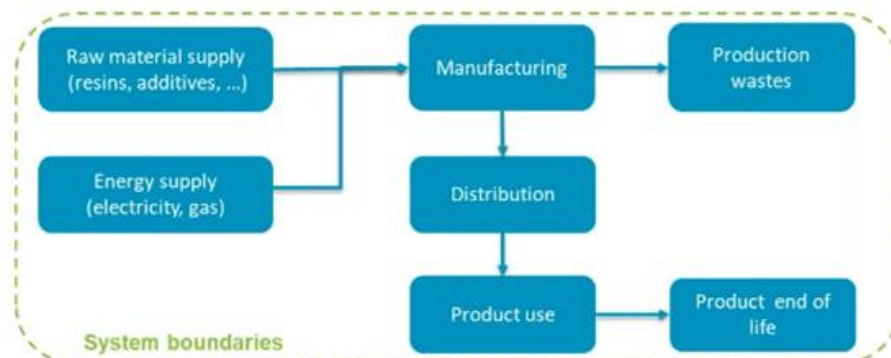


Figure 13 – System boundaries for case study #1. Source : Saunier, 2019, Webinar ACLCA

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Circularity strategies:

1. Baseline
2. Improving recycled content
3. Applying a closed loop business model
4. Using a blend of fossil and biobased resins (PE & TPS)
5. Using only biobased resins (bioPE)
6. Using biodegradable biobased resins (PHA and TPS) with current end of life (more than 80% landfilling)
7. Using biodegradable biobased resins (PHA and TPS) and ensuring composting at the end of life

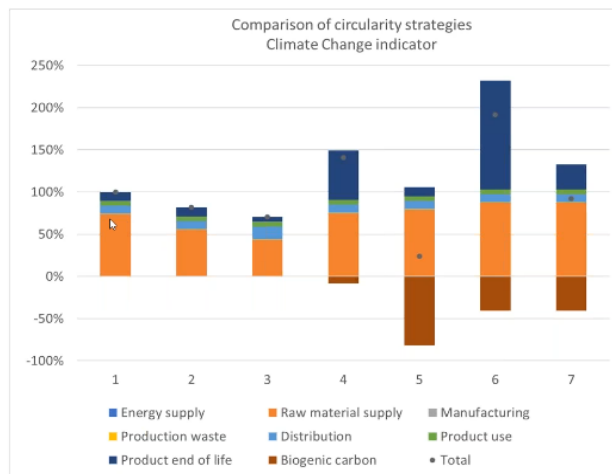


Figure 14 – Carbon footprint of circular strategies. Source : Saunier, 2019, Webinar ACLCA

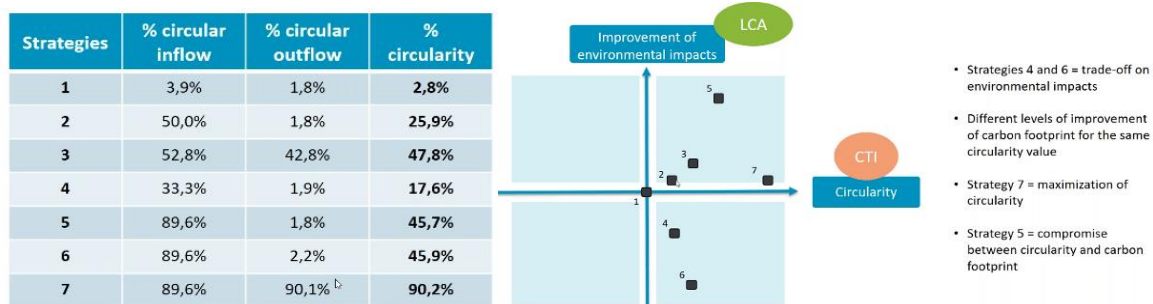


Figure 15 – Circularity score and environmental trade-off. Source : Saunier, 2019, Webinar ACLCA

As illustrated in Figures 13, 14, and 15 for case study #1, while all six circular economy strategies can significantly increase the circularity score (in different proportions), only four of these strategies (2, 3, 5, and 7) can generate environmental benefits (carbon footprint reduction). In this case study, there is no clear correlation between the two indicators.

For case study #2, Lonca et al. (2018) LCA and MCI to assess the potential of used tire management strategies to (i) avoid burden shifting and (ii) improve material circularity. The results of both case studies provide a good insight for tire manufacturers on how to manage used tires to better contribute to the CE objective. The study reveals that MCI is relevant to support circular design to preserve the specific materials that make up the product. But LCA provides a complementary perspective on a broader scope in terms of system boundaries and complementary indicators needed to measure the pressure on pollution—thus helping to avoid burden shifting, as illustrated in Figures 16 and 17.



BASELINE	
Context	Brazilian haulage trucks in 2012
Functional unit	Provide haulage truck's tires for 600 000 km and manage tires EoL
Reference flows	83 tires 72 240 l Biofuel B5

Circularity strategies:

REGROOVING	RETREADING
<ul style="list-style-type: none"> • Lifetime : +30.5% • Fuel consumption : -5.4% 	<ul style="list-style-type: none"> • Lifetime (casing) : +50% • Fuel consumption : +6.8%

Figure 16 – Description of case study #2. Sources : Saunier, 19, Webinar ACLCA ; Lonca et al., 18.

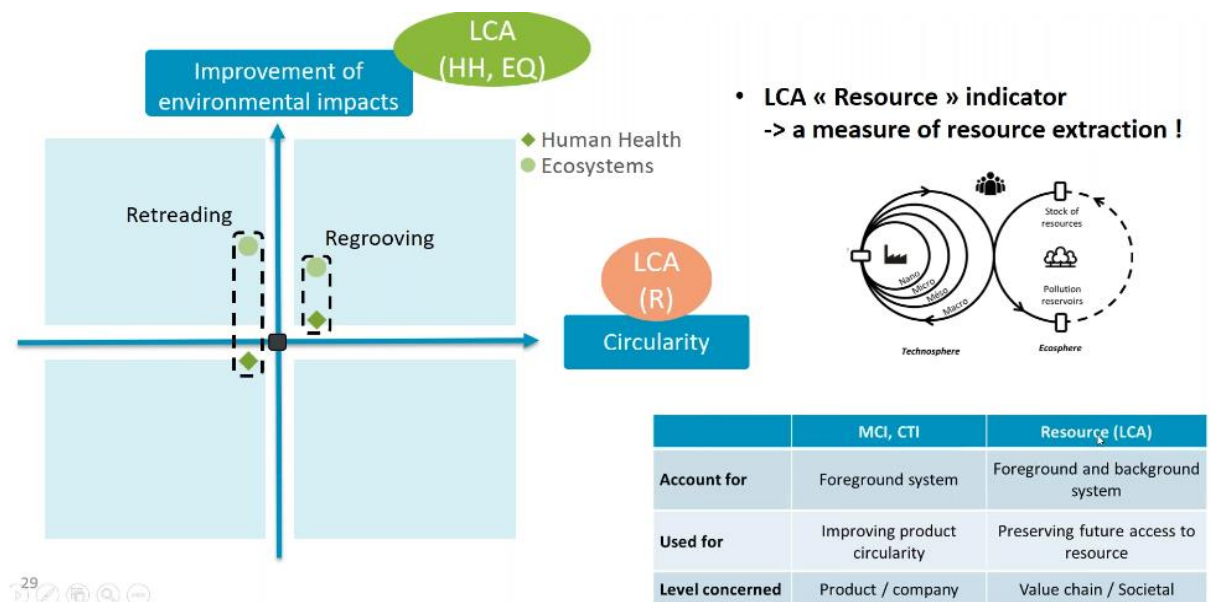


Figure 17 – Results for case study #2. Sources : Saunier, 19, Webinar ACLCA ; Lonca et al., 18.

6 Conclusion and perspectives

Identifying, selecting, and deploying the most appropriate circularity indicators is essential to both assess and improve the performance of products, companies, and regions in a circular and sustainable economy perspective. The various contributions, analyses, and recommendations - for example, the database of more than a hundred circularity indicators - can serve as a solid basis for recombining indicators based on their complementarity, as well as for enriching them with their respective specificities to build new indicators that respond to the issues of industrialists who value life cycle analysis more highly. In practice, the methodology for selecting circularity indicators, coupled with the two-dimensional graph of circularity performance and environmental impacts, can be used as a model for developing a set of indicators, coupled with a dashboard, to report on the direct and indirect environmental impact (link with LCA) of a project, the circularity potential of projects in the upstream phase, and to steer the project in the execution phase. The results of this project can also be used as a contribution to standardization in ISO/TC 323 (see Figure 18), and a presentation of these results in the mirror group "WG Metrics" of the AFNOR X30M Commission is also a prospect.

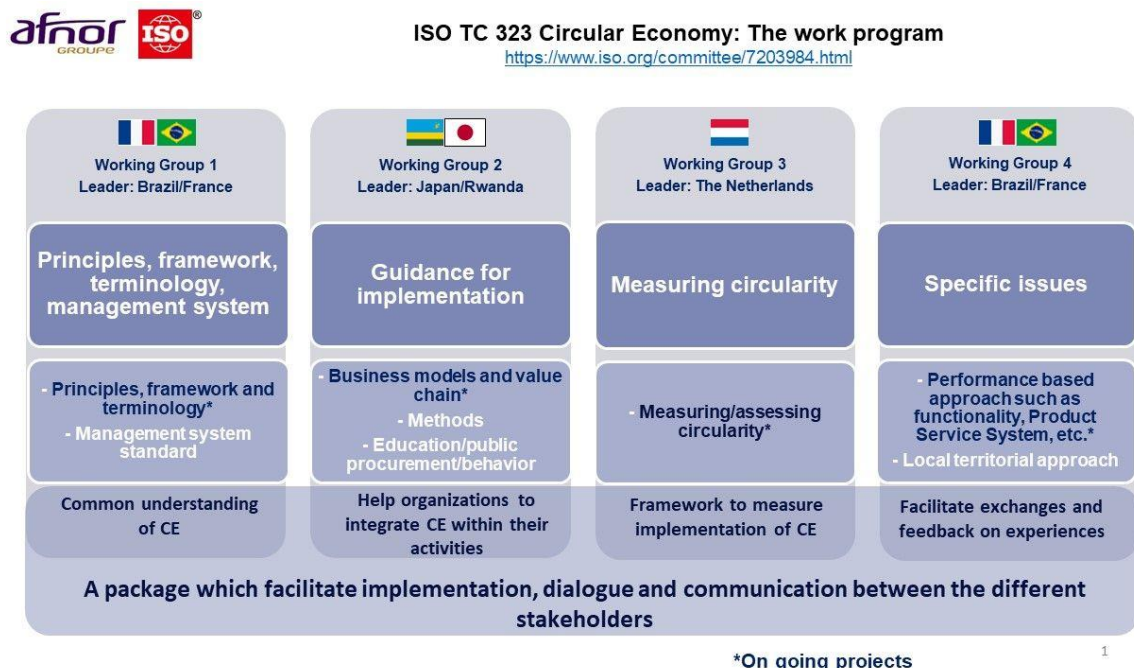



Figure 18 – Current working groups for a series of ISO standards on circularity. AFNOR.


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In order to help the user in the selection of appropriate indicators, a query tool has been developed (Saidani et al., 2019a) with the aim of making this taxonomy more easily exploitable and operational for, for example, organizations working on development projects and strategies related to the circular economy and being in search of steering indicators. This tool is intended for both industrial practitioners (product designers, engineers in design offices) and decision-makers (project managers, financial managers). For ease of use and distribution, the tool is developed on Microsoft Excel with the use of macros. The selection tool is flexible and will be updated with new c-indicators. A web-based version of this tool is also available: The C-indicators Advisor (CIA) platform (<http://www.circulareconomyindicators.com/>) is an online platform with an international scope developed by CentraleSupélec to both select and implement the right circular economy indicator(s) and unlock and track the circularity performance of products (see Figure 19). It is a free platform but requires voluntary registration.



Circularity Indicators _ The Advisor

Target the Right C-Indicators
Unlock the C-Potential of your Products



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The C-Indicators Advisor

Circular Economy (CE) Implementation Level


 Macro
 Meso
 Micro

CE Loops

 Maintain/Prolong
 Reman/Reuse
 Recycling
 All the Loops

CE Perspective (Retro- or Pro-)


 Potential



Material Circularity Indicator

MCI


Scope : Materials and Products
Loops : All the Loops
Perspective : Actual (Effective)
Performance : Intrinsic (Recirculation of materials)
Format : Dynamic Excel Spreadsheet
Authors : Ellen MacArthur Foundation (2015)



Circularity Potential Indicator

CPI


Scope : Product-centric
Loops : All the Loops
Perspective : Potential
Performance : Intrinsic (Recirculation of resources)
Format : Excel and/or Online Spreadsheet
Authors : Saidani et al. (2017)



Circular Economy Indicator Toolkit

CET

Scope : Product and Company
Loops : All the Loops
Perspective : Potential
Performance : Intrinsic (Recirculation of resources)
Format : Web-based questionnaire
Authors : Evans and Bocken (2013)



Circular Economy Indicator Prototype

CEIP

Scope : Product-centric
Loops : All the Loops
Perspective : Potential
Performance : Intrinsic (Recirculation of resources)
Format : Dynamic Excel Spreadsheet
Authors : Cayzer et al. (2017)

Figure 19 – Web-platform “The C-indicators Advisor (CIA)”, <http://www.circulareconomyindicators.com>

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