SCORELCA

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CIRCULAR ECONOMY: CONCEPTS AND EVALUATION METHODS

ENGLISH SUMMARY

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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.

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- ✓ 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.

Introduction

The concept of circular economy has recently gotten a lot of attention in France. It is generally accepted that the implied principle behind this concept is beneficial for the environment. However, the evaluation of its benefits is not systematic. Within this context, the members of SCORELCA wished to carry a project on this current topic, the main objective being to clarify the concepts, stakes and methods used when dealing with circular economy projects. More precisely, the members expressed the following expectations:

- Outline the definition of circular economy and its fundamentals to improve their capacity to communicate and to apply them,
- Understand the relations that might exist between circular economy and other existing concepts like Cradle to Cradle,
- Identify the methods and tools needed to evaluate the environmental impact of circular economy projects,
- Bring to light the potential of Life Cycle Analysis in the scope of circular economy and acknowledge the risks and points of vigilance of this methodology, specially when compared to the stakes of circular economy,
- Give operational methodological recommendation on the evaluation of material loops.

Chapter one: Basis, players and components of circular economy – State of the art

This study began with a review on the concept of circular economy (Chapter 1) and the methods most commonly used to evaluate all or some of the actions or systems within the boundaries of the concept (Chapter 2). Therefore, Ii is a review of current knowledge. Its content comes from existing documentation, French or international; it includes public reports, ordered by national organizations or not, and scientific papers obtained by the usual means of access to journals.

1. The basis of circular economy

The term “circular economy” originally comes from the academic sphere; it was used for the first time in *Economics Of Natural Resources And The Environment*[1] by two professors of Colorado University, David W. Pearce and R. Kerry Turner, in 1989. A few years earlier, in their report for the European Commission (*Jobs for Tomorrow – The Potential for Susbtituting Manpower for Energy* (Figure 1).), Walter R. Stahel and Geneviève Reday had already suggested to implement a “loop economy”

[1] Economics Of Natural Resources And The Environment, David W. Pearce, R. Kerry Turner, The Johns Hopkins University Press (décembre 1989)

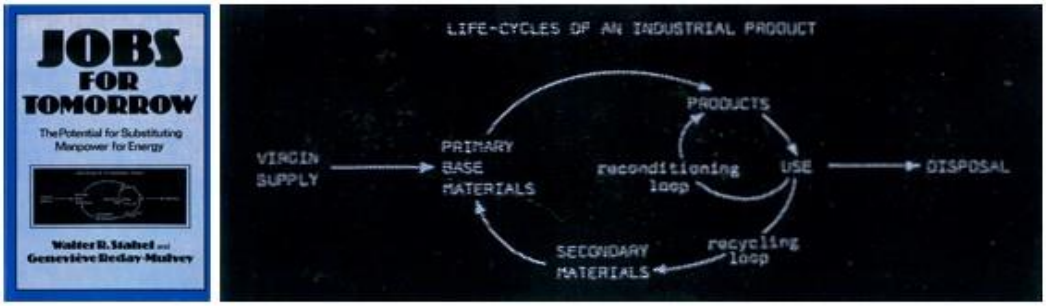

Figure 1 Loop economy (Source: Stahel et al.)

However, recently, the political and institutional spheres are the ones who have finally seized the concept and have begun deploying it more broadly.

Several sources agree on the evident link between the emergence of the notion of circular economy and the tilting of the awareness from a need to manage waste production to an efficient use of resources. The rise of raw material prices at the beginning of the 21st century, and the financial and economic crisis of 2008 had effectively placed in the forefront this growing concern for natural resource reserves.

Still, circular economy is not the only durability concept used today (Figure 2). The role of this new concept is considered uniting for some, while other see it as a rebranding of concepts that have existed for several years.

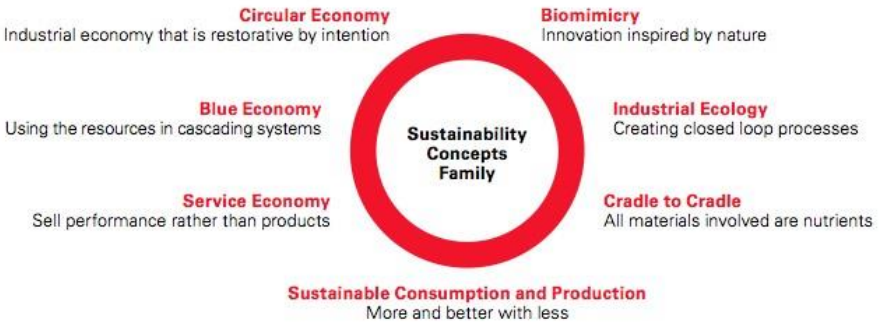

Figure 2 L'économie circulaire parmi d'autres concepts de soutenabilité (source : Lehman et al., 2014)

The first report of the Ellen MacArthur foundation, titled *Towards the circular economy – Economic and business rationale for an accelerated transition,* expresses that circular economy is rooted on several "Schools of thought", most notably *Performance economy*, *Cradle to Cradle*, *Industrial ecology*, or even *Biomimicry.*

2. Appropriation of the circular economy concept

The appropriation of this concept has been carried at the different levels, from the French national level to the European and international level. The identification of the players contributing to circular economy is a difficult task since this concept does not have a normed definition and it encompasses several broad notions (Figure 3).

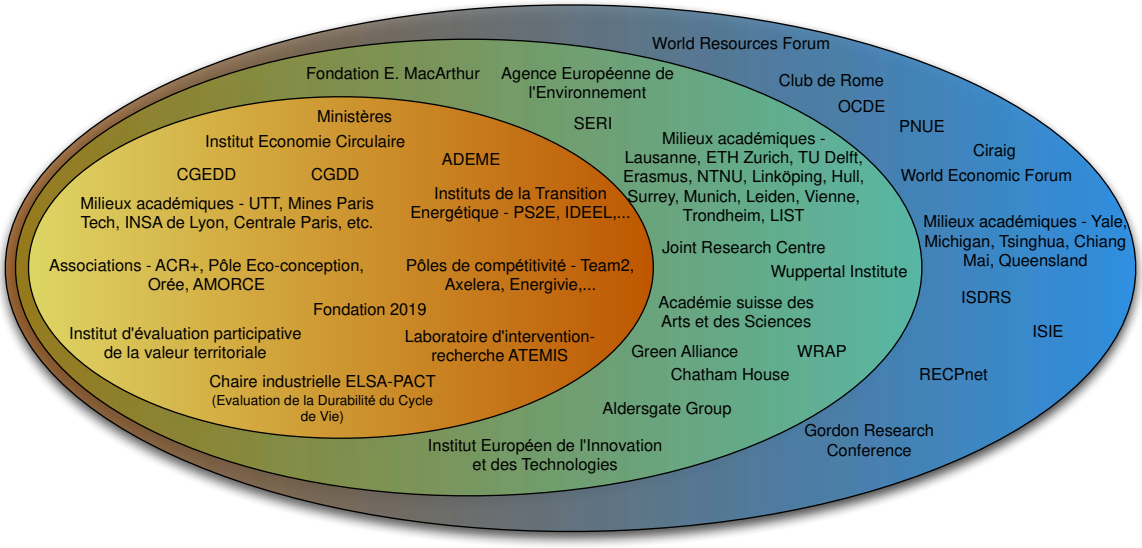

Figure 3 Cartography of major circular economy players (source: Sofies)

In 2013, the environmental conference and the conference on circular economy implementation established the major actions needed on the French territory, thiese actions are registered legally thanks to the enactment of the energetic transition and green growth law.
Other countries, like Japan, the Netherlands, China or Germany, have already implemented national policies on the topic.
For its part, Europe has made circular economy a key component for its Europe 2020 strategy, contributing to a more efficient use of resources and indirectly helping to achieve the goals set on climate change.
Finally, international organization like the OECD and UNEP have been active on the topic of resource management for several years, even if the term “circular economy” is uncommon in their recent publications.

3. What is implied by circular economy

Many circular economy players have suggested a definition for this concept that remains a notion without clear boundaries. For example, ADEME defines circular economy as “an economic exchange and production system, which aims at increasing the efficiency of resource use and at reducing the environmental impact at each step of the product’s life cycle (goods and services) while developing the well-being of each individual”. Notwithstanding the high number of existing definitions, one of the most common watchwords is the efficient use of resources, and this, in the context of a needed decoupling between economic growth and raw material demand.

Several graphic representations of the concept have been suggested as well, often centered around the “loop” notion. As a matter of fact, some academic experts have recently drawn attention to the limiting aspect of loops and ask for a larger vision, however structured around the four maturation strategies shaped by Pr. Erkman. Others have gone even further by opposing the shortcuts that lead to believe that “cycles = good” and “linear = bad” based on the apparent cyclical aspect of the biosphere.

In France, one of the most widespread representations is without a doubt the one of ADEME. In this figure, circular economy is shown as a uniting notion, linking high stakes like sustainable sourcing and responsible consumption (purchase and use), to means of action like recycling or reuse and to methodologies (or concepts) like eco-design, industrial ecology and economy of functionality (Figure 4).

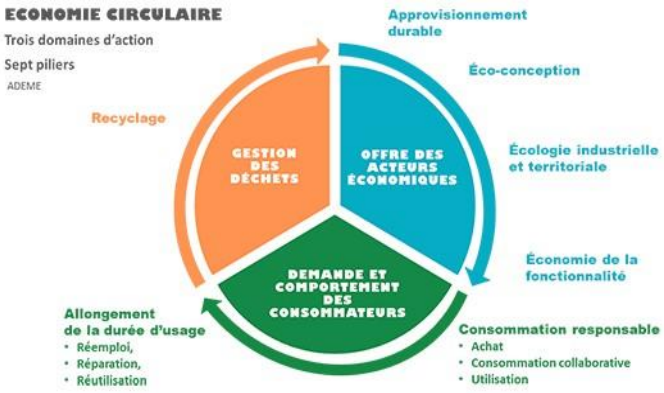

Figure 4. Representation of circular economy components (source: ADEME)

The environmental benefit of an action included in the implied components described above is generally questioned, often validated, but it deserves special attention, the result being not systematic for every product or material.

The obstacles to the implementation of circular economy were brought to light and have been presented in the report; these obstacles might be associated to the products, the markets or even the public authorities. The lack of knowledge on terms of environmental evaluation is also a hindrance and has consequences in terms of how to evaluate a circular economy loop.

4. Presentation of circular economy system evaluation methodologies

The main goal of this chapter is to lay the foundations to the understanding of the second part of this report, a review of existing work and methodologies on circular economy loop evaluation, either globally or partially.

Devoted to the presentation of circular economy system evaluation methodologies, unlike the previous section, this one is the result of the analysis of academic papers. The main goal of this chapter is to lay the foundations to the understanding of the second part of this report, a review of existing work and methodologies on circular economy loop evaluation, either globally or partially.

Three major categories of loop evaluation methodologies were identified: Material Flow Analysis, Life Cycle Assessment and Evaluation and monitoring indicators.

Chapter two: Evaluation of circular economy loop methods and stakes – State-of-the-art

According to the literature review, the goals behind every evaluation of circular economy loops can be summarized as follows:

- The evaluation allows us to obtain for a given scenario of circular economy loop impact results for different criteria.
- It can allow us to prioritize the scenarios between them and to identify the most relevant loops for a material or product.
- It can also be used to guide the implementation or the application of circular economy strategies.
- Finally, it can be used to follow up the evolution and the performance of an implemented circular economy loop

These four goals and the identified approaches are detailed below.

1. Approaches used to evaluate completely or partially a circular economy loop

Different aspects characterize circular economy loops, mainly the feasibility of the loop, its environmental impacts, its social impacts and its economic impacts (Figure 5). The selected evaluation approaches are able to evaluate these aspects partially or entirely.

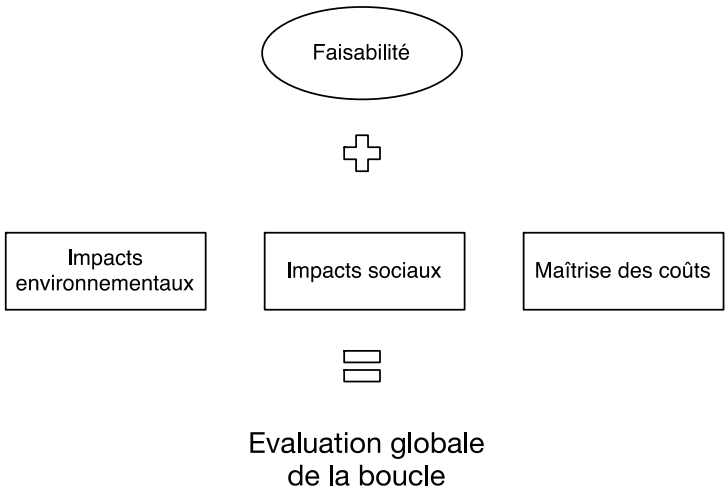

Figure 5 Representation of the aspects to evaluate a circular economy loop (Source: Sofies)

Materials and Energy Flow Analysis (MEFA) is the approach most often used to evaluate the feasibility of a recycling loop. Several stakes were however identified when carrying the feasibility evaluation. Among them:

- Identify “urban mines” (resource stocks)
- Follow-up the evolution of these reserves, most notably the dispersion of resources resulting in stock dilution
- Evaluate the amount of impurities cumulated in the resource flows
- Take into account quality loss when using secondary raw materials
- Evaluate the amount of waste that could be recycled in a closed-loop

Life cycle analysis (LCA) is the method most often used to evaluate the environmental impacts of recycling and life-prolonging loops. Even if the strong points of LCA are not questioned, some methodological issues, presented below, appear when modeling circular economy loops.

- How to exploit accessible data, like statistical or economic data, to carry an environmental evaluation
- How to build a life cycle inventory that is specific to a territory
- How to allocate environmental impacts among the different players of a recycling loop
- How to get robust results, most notably by widening the scope of the study
- How to choose the marginal scenario when applying consequential LCA
- How to take into account dissipative losses
- How to take into account recycled material loss quality after several recycling loops

The life cycle approach is equally used to evaluate economic costs through Life cycle costing. Furthermore, several ongoing projects aim at integrating the evaluation of social impacts in life cycle analysis.

Finally, several indicators have been developed by the scientific community to evaluate the environmental, economic and social impact of recycling loops, to identify scenario development key points or to follow up the performance of a circular economy strategy. One of the major issues raised by the review is the identification of indicators capable of representing society well being.

2. Approaches used to prioritize circular economy loop scenarios

The major stake when comparing and ranking circular economy loops is the definition of the best compromise for society when considering environmental, economic and social impacts.

In the light of circular economy's efficient resource use goals and the today's focus on energy consumption and greenhouse gas emissions, one of the major stakes is to rank the different issues when considering environmental impacts.

The prioritization of loops can be carried without aggregating different impact evaluation results. However, the comparison of two loops might motivate people to calculate a single impact score. The issues with this approach being:

- The aggregation of impacts expressed in different units
- Avoid any double-counting
- Establish weighting factors for different impact categories.

3. Approaches used to apply circular economy loops

Circular economy suggests the implementation of different kinds of loops to enhance resource use efficiency. Certain pillars of ADEME's concept can allow us to reduce our environmental impact along each step of the loops, as it is done with eco-design.

The scientific paper review allowed us to identify the life cycle based methods destined to encourage eco-design, as well as the Material Flow Cost Account based methods that enable the development of clean production on an industrial site.

Ultimately, the stakes of using evaluation as a decision aid tool rely mainly on the identification of indicators capable of representing circular economy goals.

4. Approaches used to follow up circular economy loop results

The evaluation of circular economy loops can also be used to follow up their results, namely, to analyze the evolution and the performance of implemented loops.

The main evaluation methods are based on the use indicators meant to monitor system evolution and to rank the performance of a system according to the goals set beforehand.

The challenge behind this performance evaluation lies on the identification of the indicators representative of each possible circular economy loop.

Chapter Three: Using LCA to evaluate the environmental performance of recycling loops in a circular economy context – methodologies, stakes and operational suggestions

1. Introduction: From the state-of-the-art to the major methodological issues behind recycling loop evaluation

The literature review has showed LCA as the most commonly used method to evaluate the relevance and the environmental performance of material-loops. However, several methodological issues linked to LCA have been noticed and have been presented in the preceding chapters. These issues can be classified in 7 categories:

- **Issues linked to resource evaluation**
- **Issues linked to material quality**
- **Issues linked to future evaluation**
- **Issues linked to impact ranking**
- **LCA issues nonspecific to Circular Economy or loop evaluation**
- **Issues not linked to LCA**

Some of the issues showed are not exclusive to the environmental evaluation of material-loops and are widely known by the LCA community. Therefore, only issues related to material-loop evaluation and to the interpretation of its results have been discussed in this chapter.

This chapter, detailed in the full report, is meant to guide LCA practitioners through each step in the construction of an environmental evaluation, from the goal and scope definition to the analysis, interpretation and exploitation of results, the goal being to evaluate the environmental performance of circular economy projects.

2. Definitions related to material-loop

Most Circular Economy projects are characterized by the implementation of one or several material-loops, the aim being to reduce resource consumption and to limit the amount of waste produced.

In this report, material-loops have been defined as any system where one or several end-of-life flows are treated without destroying them to produce secondary raw materials and to limit

the use of primary raw materials. These loops can deal with materials (ex. Steel), components (ex. Engine part) or end-of-life products (ex. Computers). Material loops therefore include recycling, reuse and reemployment, but also the agricultural reuse of organic waste. Material-loops can be classified in three categories:

- Closed loops
- Open loops
- Cascade recycling

3. Material-loop evaluation: Goal definition

Circular economy is a wide and interdisciplinary topic. However, several common goals have been more or less explicitly defined (ex. Reducing resource use, promoting and encourage all “effort”…)

Just like circular economy, one of the first steps in LCA is the definition of one or several goals. This step allows us not only to define the study’s point of interest, but also to frame the following steps. Defining the goals precisely is the best tool to identify the methodological choices that must be made to insure the progress towards the set goals. Therefore, the use of LCA to evaluate circular economy projects implies the inclusion of circular economy goals in the goals of the study. These may have an effect on:

- The scope of the study
- The reference flows and functional unit
- The models used to evaluate impacts
- The methodological choices and the selected environmental indicators

However, LCA is incapable of taking into account and evaluating all circular economy goals. In some cases, LCA might event clash with these objectives; it is therefore necessary to use complementary evaluation methods or specific indicators.

4. Including circular economy goals in the scope of the study: Waste LCA/Product LCA

The first choice every LCA Practitioner must make when defining the scope of the study is on the **type of LCA** he will carry.

LCA allows us to evaluate a system’s environmental impacts in relation to a given function. When analyzing circular economy projects, the valuated function is often centered on material-loops or on waste management options. In any case, end-of-life is at the heart of these projects’ LCA.

Two complementary approaches were developed to evaluate end-of-life in LCA :

- **Waste LCA**
- **Product LCA**

Waste LCA, which is less frequently used in the LCA community, is the ideal tool to explore the end-of-life stage in detail. These two tools are complementary and can be used to answer different questions as shown in the figure below.

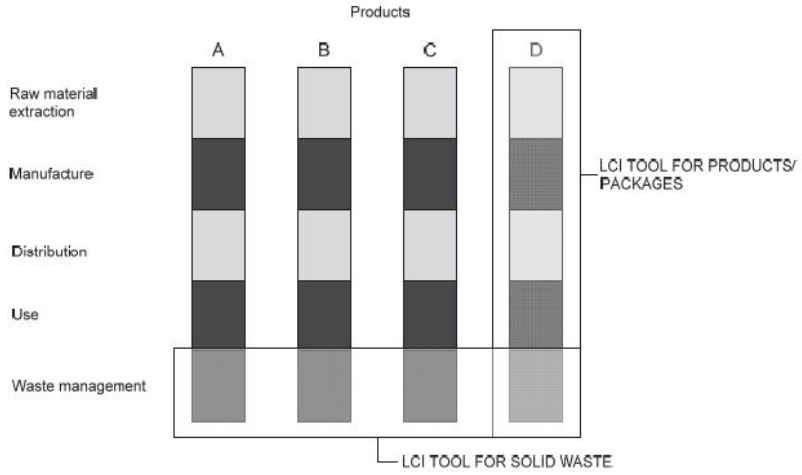

Figure 6: Waste LCA vs. Product LCA (Colemant, Masoni, Dryer, & McDougall, 2003)

The choice between both types of LCA strongly depends on the evaluated waste deposit, the project holder's range of actions and the preset goals of the study. Thus, if the goal is to evaluate the environmental impacts behind the management of a diverse waste deposit (ex. Municipal solid waste), Product LCA seems like an unlikely choice. The information needed to carry such a study would be too important and hardly accessible for an LCA practitioner or a waste manager

When carrying Waste LCA, the practitioners must be alert on the definition of:

- The scope
- The functional unit
- The evaluation of material-loop benefits

5. Including circular economy goals to the scope of the study: material-loop scope and modeling in product LCA

Once the material-loops identified, it is necessary to define the methodology that will be uses to evaluate them. The choice of methodology will largely depend on available data, and on the type of loop under study.
In some cases, it is possible to evaluate the cyclic reuse of material pragmatically by adjusting the scope of the study, also known as system expansion. This method is particularly useful to evaluate closed loops, where is loop is similar or identical to the previous one.
However, this approach is not always suitable. System expansion can become a complex task and can even be impossible to apply. Moreover, when product functionalities differ from one loop to the next, the results become hardly exploitable and the need to allocate the environmental impacts between the different processes or cycles arises.
As mentioned by Osset et al (Osset, Clauzade, Hugrel, & Palluau, 2012), ISO 14040/44 leaves modeling of recycling operations open to interpretation. However, the French, European and sectorial methodological guides have brought some precisions on the subject, helping LCA practitioners in the decisions they must make.
And even if each material-loop is unique, it is possible to find some common ground among them. Several evaluation methods have been developed based on this factor:

- **100 – 0**
- **0 – 100**
- **50 – 50**
- **Cut-off**

The choice of allocation rules remains largely subjective. For the 0-100, 100-0 and 50-50 approaches, the choice depends mostly on analysis of the supply and demand of secondary raw material in a given market and on how the secondary raw material should be positioned in that market. The decision is thus heavily linked with the goals defined beforehand and should allow the practitioner to take into account some of the circular economy goals defined.

6. Integrating circular economy goals in the functional unit

Like the scope of the study, the functional unit should be defined according to the goals of the study and the circular economy goals that we wish to evaluate.

7. Evaluating material quality loss

Circular economy and material-loop implementation foster the reuse of resources. And if recycling limits the use of primary raw materials, it can also lead to a loss of material quality. The loss of physical properties is, as a matter of fact, a recurrent problem in recycling operations. Material quality loss is actually the origin of open loops, leading to the apparition of the term *downcycling*.

Some of the developed end-of-life allocation formulas introduce a Q_s/Q_p factor to solve this issue. In this formula Q_s represents the quality of the secondary raw material, while Q_P refers to the primary raw material quality. Q_s/Q_p is therefore the dimensionless ratio used to approximate the differences in quality that might exist between to materials as a consequence of downcycling. The use of this factor shouldn't however be systematic as it could be redundant.

8. Evaluating future circular economy projects

Commonly used, Attributional LCA is a photograph taken at a given moment of the environmental impacts of a product or service. The temporal representativity of such a study would be the date in which it was carried. This kind of approach can hardly evaluate the impacts of a future development, something that characterizes most Circular Economy projects.

One possible solution would be to use the consequential LCA approach. This method is capable of taking into account market evolutions to evaluate the environmental consequences of developing a new technology or making a precise decision. By studying the environmental impacts associated with the implementation of a recycling loop or with the substitution of raw materials by recycled materials, it is possible to evaluate the effect this evolution might have on the environment or the market. Applying the consequential approach demands specific knowledge on the global market and on the evaluated sector. The SCORE**LCA N° 2012-01** (Centre de Recherche Public Henri Tudor, 2013) report gives a detailed review of the methodological issues to take into account when applying consequential LCA.

9. Resource indicators – Issues behind the environmental evaluation of resource use impact in LCA

One of the main goals of circular economy is to limit the global consumption and losses of natural resources in order to insure their availability for future generations. And even if it is

commonly accepted by the scientific community that a sustainable use of natural resources is necessary, no consensus exists on its definition and on the best way to measure ***resource use***.

For De Bruille (De Bruille, 2014), the following issues must be quantified if a robust method to evaluate resource depletion is desired:

1. Resource functionality
2. The users adaptability mechanisms when faced by resource depletion, including the resource substitutability by resources with similar functions
3. The distinction between extracted resource and dissipated resource
4. The effect of resource dissipation on the users

Taking into account these issues, De Bruille developed a new MidPoint resource depletion calculation method for ImpactWorld+. This method is currently the only one that integrates resource dispersion in its calculations. This inclusion seems as a necessary step as resource depletion is linked to the non-availability of resources and not to their absence in the earth's crust.

However, this issue brings to light a new challenge: is every use of resources equivalent? Shouldn't the impact of an activity on resource depletion be measured by its participation to the phenomenon? As a matter of fact, one of the goals of circular economy is the reduction of dissipative losses and the optimization of the tightness of material loops.

Thus, LCA is currently incapable of solving every issue behind the evaluation of resource depletion. It therefore needs to be complemented by other methods (like MFA) that focalize on this aspect.

10. Prioritizing environmental impacts

The evaluation of different material loops scenarios using LCA leads to different impact category results. If the ranking of these scenarios varies according to the different impact categories, it is necessary to prioritize these impacts. The need for impact prioritization is an issue of LCA in general and not exclusive to circular economy projects. It is the key to an efficient environmental management. However, as new developments have recently come to light, it was decided to treat this aspect of LCA in this chapter.

Often, environmental impacts are normed using "person equivalent" as a unit. This approach is however criticized as some consider the current impacts of a person as an unreliable unit to establish action priorities.

Björn & Hauschild (Bjorn & Hauschild, 2014) have recently offered some new elements to solve this difficulty. They believe that the importance of an environmental issue could be analyzed by quantifying its contribution to the overall impacts generated by humanity on earth. This approach, called Planetary Boundaries (Rockström, Steffen, Noone, Persson, & F. S. Chapin, 2009) aims at identifying and quantifying Earth's limits if we want future generations to live and grow.

Several scientists agree on the importance on taking into account the global context when measuring environmental impacts. Based on this belief, an initiative, called Science-Based Targets was launched in 2014 by WRI, WWF, CDP and UNGC. Their goal is to use Planetary Boundaries to define the objectives in terms of GHG emissions.

Conclusion

The growing awareness on the need to use natural resources efficiently dates back to the 70's. However the idea became widespread at the beginning of the 21st century with the rise in raw material's prices. The financial and economic crisis of 2008 only amplified the phenomenon, leading the way to the development of circular economy.

Nevertheless, the concept of circular economy appeared in the midst of several sustainability concepts that were developed earlier, in the 80's and 90's. Among these, the better known are *Performance economy*, *Cradle to Cradle*, *Industrial ecology*, *Biomimicry* and *Green economy*

The advent of circular economy is largely based on its adoption by French, European and International groups. Which in turn, has lead to the appearance of circular economy, creating a concept with a blurred definition.

The scientific literature review has also shown that circular economy is not a research field on its own right. However, when scientists decide to study material loops, they use three types of methods: Material Flow Analysis, Life Cycle Assessment and Performance indicators.

Furthermore, the literature review shows that circular economy loops can be evaluated to establish their feasibility, to evaluate their social, economic and environmental impacts, but also to compare and rank different loops, to accompany their establishment and to follow-up their performance. Behind each of these goals, the methodological issues were defined, such as the inclusion of dissipative losses or the taking into account material quality loss.

Some of these issues are not exclusive to material loop evaluation and are largely known by the LCA community. It was therefore decided that only issues directly linked to material loops would be studied in detail. This analysis was carried following the steps of an LCA practitioner, each step of an LCA being decisive to insure robustness.

Thus, LCA practitioners must insure the coherence between the goals they have set for their evaluation and the goals of circular economy behind the evaluated project. And even if LCA might not be able to evaluate every objective, the definition of the goals is essential to define the type of LCA, the scope of the study, the functional unit, the environmental indicators and the choice of prioritization method.

Circular economy appears today as a method without a proper research field. However, methods capable of evaluating circular economy concepts have been developed in academia. Consequently, it is difficult to generalize the best practices when evaluating circular economy loops. This report is a first step in the evaluation of circular economy project and it could be improved with complementary works.