

INNOVATIVE METHODS FOR ASSESSING THE ENVIRONMENTAL IMPACT OF WASTE

Summary of the study

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The SCORE LCA association is a study and research structure dedicated to Life Cycle Assessments (LCA) and their environmental quantification. Its aim is to promote and organise cooperation between industrial, institutional or scientific actors in order to promote a shared and recognised evolution, at European and international level, of the Life Cycle Assessment methodology and its implementation.

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- ✓ The information and conclusions presented in this document have been drawn up on the basis of scientific and technical data and existing regulatory and normative framework at the time of the publication of the document.

Scientific summary

Introduction

The perception of waste has changed significantly in recent decades: yesterday perceived as streams of material without any value, **waste is now seen as a real resource**. This transition from the concept of waste to that of a resource has resulted in the integration of the **circular economy concept**, a true paradigm shift, aimed at creating a new thinking of “virtuous loops” in which recyclable materials are reinjected into the economy: the goal is to maximise reuse and recycling, and minimise waste generation.

In the European Union, circular economy has gradually become part of the legislative and political agenda. To mention just a few key texts: the European directive No 98/2008 EC on waste management specifically sets the hierarchy of waste treatment methods based on the priority principle of “reduce, re-use, recycle”, the roadmap “*for an efficient Europe in the use of resources*”, published in September 2011 further strengthens the link between waste and resources, and finally, the European Commission has published its “**circular economy**” package which includes an ambitious action plan covering the entire life cycle of products and services, including proposals for revising waste directives, for example, by setting a recycling target of 65% for municipal waste and 75% for packaging waste by 2030.

Therefore, we must change our view on waste and on its value: waste and resources are two sides of the same coin. Landfills are now considered as potential material reserves: it represents a large quantity and the concentration of certain materials in the stored products is greater than that of the initial ore in the earth’s crust. We even talk about “**urban mines**”.

Since then, **how is this change in the perception and vision of waste as a resource reflected in environmental assessments and their recent evolutions?**

Simultaneously, the ability to **assess the impact of waste management channels**, especially in environmental terms, has become an important issue for public and private decision-makers. Many methods and approaches can be used as a decision-making tool for waste management. An LCA is a relevant method, but other methods of systemic analysis are also used, such as Strategic Environmental Assessment (SEA), Risk Analysis (RA), Material Flow Analysis (Material Flow) Analysis - MFA), Substance Flow Analysis (SFA), Input-Output Analysis (IO), Energy Or Exergy Analysis, Entropy Analysis...

Among these methods, the **LCA has a strong resonance with public authorities**: as an example, in its waste strategy, the European Commission encourages the use of the life cycle thinking and the LCA as complementary approaches to the hierarchy of waste treatment introduced in the European directive No 98/2008 EC to support decision-making on waste management using actual elements from an environmental point of view. However, other methods also provide interesting additional insights on waste management channels.

Due to the specific nature of waste management activities, assessing their environmental performance involves major issues in terms of calculation methodology:

Challenge	Issue(s)
1- Multifunctionality management	The multifunctionality of waste management leads to issues in defining allocation rules: to which life cycle(s) should the environmental impacts and benefits of waste management be allocated to, and which rules should be used? In addition, recycling potentially allows the material to be included in several life cycles. Therefore, how can the different life cycles of a material be better taken into consideration when choosing the accounting and allocation method to fairly assess recycling? Should the impacts of the production of a primary material be more evenly distributed over the different life cycles?
	Waste recycling overlaps two life cycles. Therefore, how to set up the boundary of the system assessed?

Challenge	Issue(s)
2- Data quality	Waste management activities are complex to understand and to transcribe into an LCI with good representativeness: these activities have multiple operators, material, covering complex physical and chemical phenomena and occurring over varied timescales (short term in the case of incineration or long term in the case of landfill). The data needed to take these processes into account are often fragmented or not representative of the specific context of the study.
	With regards to data quality, and given that processing is constantly evolving, how representative is the existing data for modelling the treatment processes of long lifetime products (construction products, goods, etc.), which will be sometimes implemented in several decades? In the same vein, if we chose a substitution method, what will the recycled materials be replaced with in several decades (this an issue to the difficulty in apprehending the function provided by the resources in a context of permanent technological evolutions)?
3- Waste characterisation	Because waste management activities require several stages, waste characterisation throughout the treatment process stages is very complex.
4- Understanding the quality of secondary material produced from recycling	Recycling provides secondary material that is reinjected into the economy. One of the barriers to a greater integration of secondary material in the manufacture of new products is the lack of visibility as to the quality of the secondary material in relation to the primary material (uncertainty about the quality of the material, lack of standards, labels, etc...). This issue echoes the difficulty in identifying the relevant quantities to transcribe the different quality levels of the secondary material when obtained through different recycling processes. In addition, the value to be used will depend on the application into which is integrated this secondary material, depending on whether this material is used for its mechanical properties, electrical conductivity (in the case of metal cables) or other qualities. Is the economic value of the secondary material, while fluctuating over time, a relevant value, correlated with the quality of the material?

Other issues are added to these difficulties of selecting the most suitable method and data:

- For the practitioner, the complexity of environmental accounting methods for waste management activities sometimes leads to difficulties in implementing these methods in the LCA software.
- It is difficult for non-experts to understand these methods, their links with the physical reality of industrial processes, the results of these methods, and the influence that selecting one or another method may have on the market orientation and the efforts of the various actors in a sector.

Objectives of the study

To address these issues, research efforts are being made to improve the robustness and relevance of environmental assessment methods for waste management streams, and methodological developments are still underway. How are environmental assessment methods evolving? Are issues mentioned above better understood by recent methods or are currently being developed? Is there a link between assessing the resource consumption and the issues of waste management?

In 2010, BIO Intelligence Service (having joined the Deloitte Sustainable Development team in 2013) produced on behalf of the RECORD association state of the art rules for taking into account the end of life in an LCA. Since then, some SCORELCA projects have also addressed various environmental assessment methods for waste management. It was key for SCORELCA members to take stock and understand recent developments.

The purpose of this study was therefore to identify all existing or developing innovative methods for assessing the environmental impact of waste, to carry out a critical analysis of these methods and to provide operational recommendations to assist LCA practitioners in their studies.

The objectives of the study were as follows:

- Identify all existing or developing innovative methods for assessing the environmental impact of waste and carry out a **critical analysis of these methods**.
- Make the more relevant methods directly operational for SCORELCA members, especially through the development of **practical fact sheets**.
- **Focus on two major issues of waste assessment**: ways of taking into account and assigning “second-life waste”, and taking into account the environmental “residual value” of waste.

The work was carried out in two phases:

- A **Phase 1** including the following:
 - ✓ **Identification of** quantified environmental assessment **methods** for waste management used in France and abroad and applicable to the different categories of waste, with a particular focus on innovative methods,
 - ✓ Preparation of a **critical analysis for the most relevant methodologies and their applicability** in the context of SCORELCA members,
 - ✓ Development of **eight fact sheets** for these methods to be directly operational for SCORELCA members, especially through the development of practical fact sheets.
 - ✓ **Identification of evolution perspectives for the methods**, especially for methods still under development.
- A **Phase 2** focussing on two major issues of waste assessment, namely:
 - ✓ A first focus on **methods for taking into account and assigning “second life waste”**,
 - ✓ A second focus on **taking into account the “residual value” of waste**.

Review, applicability and perspectives

Identification and selection of methods to be analysed

In this part of the study, a major literature review was carried out on the methods for assessing the environmental impact of waste management, the scope of which was as follows:

- Purely “LCA” methods,
- Methods combining LCA and other methodological approaches (such as a combination of MFA / LCA, LCA / risk analysis, etc.),
- Other non-LCA methods (such as risk analysis, cost-benefit analysis, Multi-Criteria Decision Making).

The research focused on methods developed since 2010: some end-of-life LCV calculation methods already well documented and implemented in the range of commonly used approaches (e.g. “100:0”, “0:100” or “50:50” approaches, inventory method, original Product Environmental Footprint formula, etc.) were mentioned in the literature review but were not included in the scope of methods to be analysed.

In order to complete this literature review, LCA practitioners and method developers as well as international relays were surveyed. This provided the following results:

- Respondents did not identify a missing issue in the environmental assessment of waste management against the list of identified issues (presented above),
- One respondent mentioned a method of potential interest for the study: the method implemented by Récyclum, Eco-Systèmes and Bleu Safran for the production of an LCI for the end-of-life management of 7 EEE flows as part of the WEEE framework.

At the end of the literature review, a literature database was compiled containing 93 identified references, of which 84 were published as of 2010, the remainder between 2006 and 2009. A pre-selection step, followed by a prioritisation step made it possible to identify the **8 methods listed in the following table for an in-depth analysis**.

Table 1 - List of selected methods that have been thoroughly analysed in the study

Title	Author(s)	Year	Method	Method fact sheet
The “Integrated formula” for modelling the recycling, the energy recovery and the reuse in an LCA	Wolf M-A., Wolf (Chomkhamsri) K., Ardenne F	2013	Integrated approach	Fact Sheet No.1
1. The Multi-Recycling-Approach as a new option to deal with the end-of-life allocation dilemma (presentation at the ACLCA LCA XII conference, Tacoma, 2012) 2. and: 3. Ökobilanz nach ISO 14 040/44 für das multirecycling van stahl	Neugebauer S., Finkbeiner M.	2012	“Multi-recycling” approach	Fact Sheet No.2
Environmental assessment of the sorting and recycling of plastic household packaging other than bottles and containers (final study report for the ADEME and Eco-Emballage)	Hugrel C., Palluau M.	2014	Calculation of the residual value of the waste	Fact Sheet No.3
Discussion on methods to include prevention activities in waste management LCA	Nessi S, Rigamonti L., Grosso M	2013	Inclusion of prevention in waste management LCAs	Fact Sheet No.4
“Life Cycle Assessment of Mixed Municipal Solid Waste: Multi-input versus multi-output perspective	Fiorentino G., Ripa M., Protano G., Hornsby C., Ulgiati S.	2015	“Multi-input” and “multi-output” approach	Fact Sheet No.5
Methodology of supporting decision-making of waste management with material flow analysis (MFA) and consequential life cycle assessment (CLCA): case study of waste paper recycling	Sévigné-Itoiz, E., Gasol C. M., Rieradevall J., Gabarrell X.	2014	Combining MFA / LCA	Fact Sheet No.6
Environmental consequences of recycling aluminium old scrap in a global market	Sévigné-Itoiz, E., Gasol C. M., Rieradevall J., Gabarrell X	2014		
Combined material flow analysis and life cycle assessment as a support tool for solid waste management decision making	Turner D. A., Williams I. D., Kemp S.	2016		
“Circular Footprint Formula”: approach recommended by the European Commission as part of the PEF-OEF pilot phase	European Commission	2016	Circular Footprint Formula (CFF)	Fact Sheet No.7
LCI for the end-of-life management of constituent materials for electrical and electronic equipment in the approved WEEE sector	Eco-systèmes; Récyllum; Bleu Safran	2016	Combining MFA / LCA	Fact Sheet No.8

The “Fact Sheets” are available in the final report of the study.

Conclusions and perspectives

Two axes for analysing the methods have been suggested:

- A first axis aimed at carrying out an **analysis of the methods with regards to the identified challenges of the environmental waste assessment**;
- A second axis aimed at **analysing the methods according to the context and the objectives of the studies** in which they could be implemented: in product-oriented LCAs and waste-oriented LCAs as well as in potential applications of the results obtained.

Ways forward have also been suggested in the final part to work out how to deal with the issues identified but currently not covered by the methods, identify ways of improving each method and identify possible additional studies or monitoring to be carried out by SCORELCA.

❖ **Analysis of methods with regard to the identified waste management issues**

The specific aim of this phase of the study was to answer the following question: **are issues of the environmental waste management** assessment addressed by innovative methods identified in Phase 1 of this study?

The issues considered here are limited to those of an LCA applied to waste management, as the methods analysed in this study are all methods based on LCAs. The issues considered are as follows:

Table 2 - Summary of identified issues in an environmental waste management assessment

#	Issues identified
Issue 1	Allocation of environmental benefits and impacts of materials or energy recovered between two successive life cycles
Issue 2	Representativeness over time of waste treatment processes for long-lifetime products (such as buildings)
Issue 3	Complexity of mapping the structure of waste management channels (such as the complexity of identifying all stakeholders involved in a processing channel, complexity of mapping the succession of processes required in waste management systems, etc.)
Issue 4	Characterisation of the waste throughout the processing channel (ability to identify and assess the different impurities and the quality of the fractions of recycled materials resulting from the processing operations)
Issue 5	Availability of robust and representative life cycle inventories (LCI) for processing operations (e.g.: fugitive air emissions and emissions due to leachates in landfill sites)
Issue 6	Availability of robust and representative life cycle inventories (LCI) to capture the benefits of material recycling and energy recovery
Issue 7	Availability of characterisation methods to assess the toxic impacts of landfill leachates
Issue 8	Taking waste into account as a real resource and not as a free unavoidable resource from an environmental point of view. E.g.: taking into account an intrinsic “value” of waste / questioning of the “zero burden” approach commonly accepted when waste entering the processing system is considered as having no impact, the impact of steps upstream of the collection being allocated to the primary function of the material in the waste, etc.

The main points emerging from this analysis are as follows:

Assessment of the methods analysed with regards to the general LCA framework:

If we consider the methods in terms of their contribution and their relationship to the general methodological framework of LCA, as defined in ISO 14 044, the following elements can be observed:

- Methods such as a combination of MFA/LCA are of interest generally “upstream” of the implementation of the LCA as such: these methods are mainly used to provide more robust data for **establishing the life cycle inventory** for the system assessed, more specifically by allowing better traceability of the different flows of materials or substances.
- Other methods are at the heart of the LCA, especially in the **life cycle inventory calculation**, specifically all methods allocating environmental benefits / impacts between successive life cycles (integrated approach, multi-recycling approach, Circular Footprint Formula).
- Implementing certain methods fits in a **cross-sectional manner to the general framework of the LCA**: this is the case of the “Multi-input / multi-output” method. The specific principles of the method affect different stages of the LCA implementation, from defining the objectives and scope of the study to interpreting the results.
- Finally, other methods (taking into account the residual value of waste) provide additional information **“downstream” of the LCA**, by suggesting alternative methods to the “traditional” accounting of certain environmental impacts (such as the primary energy consumption in the case of the method of taking into account the residual value of waste).

Overview of the coverage of issues identified by the methods

With the arrival of the concept of circular economy and the hierarchy of management modes established in Directive 2008/98/EC, waste tends to be increasingly considered as a resource. Among the methods assessed, two specifically take into account this point of view: the method which takes into account the residual value of waste and the “multi-input” / “multi-output” approach.

Other key issues of circular economy such as waste prevention are only partially covered in literature. Most studies assessed during the literature review deal with “traditional” processing (recycling, energy recovery, landfilling) and, paradoxically, very few studies look at the management methods considered as priorities in the management method hierarchy.

“Product-oriented” LCA versus “Waste-oriented” LCA

Among the methods for assessing the environmental impact of waste management based on the LCA method, two approaches can be distinguished according to the overall objective of the study and the nature of the system assessed:

- The **product-oriented LCAs**, called “cradle to grave” and for which the scope includes all stages of the life cycle of the assessed product. The waste generated at the end of the product’s life is then integrated into the limits of the system as a step of the cycle among others. The related impacts are scaled to the functional unit defined upstream.
- The **waste-oriented LCAs**, dealing solely with the management of one or several waste streams. With this approach, it is possible to compare waste processing lines with one another.

The eight methods assessed in this study are sorted into two main approach categories:

Table 3 - Classification of environmental waste management assessment methods analysed in the study

	PRODUCT-ORIENTED LCA	WASTE- ORIENTED LCA
Overall objective with regards to waste management	Analyse the contribution of the end of life of the product to the impact of the full life cycle of the analysed product	Measure and/or compare the environmental performance of one or more waste processing channels
Example of a typical functional unit	Example for a consumer product: “Use X product unit(s)” Example for packaging: “ <i>Protect 1kg of product from the conditioning step until the product is used</i> ”	“Collect and process/recover 1 ton of waste”
Classification of methods included in this study	Integrated approach “Circular Footprint Formula” “Multi-recycling” approach	Calculation of the residual value of the waste Inclusion of prevention in waste management LCAs “Multi-input” and “multi-output” approach Combining MFA / LCA

Analysis of methods according to potential targeted applications

An analysis of the strengths, weaknesses, opportunities and threats (SWOT) of the selected innovative methods was carried out with regards to different groups of potential applications within the meaning of the ILCD.

The application groups considered in this analysis are as follows:

- Group 1:
 - Identification of Key Environmental Performance Indicators (KEPI) for a product category as part of an ecodesign / simplified LCA approach,

- Analysis of the weak points of a given product (“weak point analysis”),
- Advanced ecodesign / design approaches favouring recycling, simplified LCA study / “KEPI”
- Group 2:
 - Comparison of specific goods or services,
 - Benchmark of products against the average of the category to which they belong,
- Group 6: public policies - prospective analyses on the penetration rate of technologies or material strategies,
- Group 8: Institutional or site environmental statement, including calculations of indirect impacts of an Environmental Management System (EMS).

Other applications or groups of applications are suggested in the ILCD but have not been included in this analysis, as they are considered less relevant to the needs of SCORELCA members. The detailed SWOT matrices for the methods are presented in the final report of the study.

❖ *Perspective*

By analysing the methods and putting into perspective the results of the analyses, it was possible to identify the following main improvement axes:

- Generalise the concepts or principles on which the methods are based;
- Remove methodological biases in the methods in order to improve their robustness;
- Improve the operationality of methods for easier implementation by practitioners.

Areas for improvement were identified more specifically for each of the methods included in the scope of the study. These are detailed in the final report of the study.

In-depth study A: Multi-cycle life allocation

The aim of this part of the study was to analyse the methods for allocating the impacts of waste treatment and recovery processes (and overall, the processes for the production and treatment of materials) as well as any related benefits from recycling and recovery, to product life cycles other than those where these processes are physically involved: we speak of “multi-cycle” allocation methods. Such an allocation can be made on the first life cycle of the assessed material (its first use after its production as primary material), on the life cycle following the assessed life cycle, or on the previous life cycle for the recycled content, the consumption of secondary energy or repaired components, or even throughout all the life cycles of the products in which the material is used before being entirely discarded or dispersed.

To fully understand the issues of different methods of multi-cycle life allocation, the following elements have been suggested as part of this study:

1. Specific methods have been analysed (theoretical analysis, SWOT analysis - Strengths, Weaknesses, Opportunities and Threats), to better understand in practise the pros and limitations of different types of approaches.
2. General considerations have been made on multi-cycle life allocations.

Analysis of specific multi-cycle life allocation methods

There are three different ways to look at the end-of-life in an LCA:

- **The material approach**, which focuses on the average impact of a material throughout its life. The impacts are calculated by kg of material.
- **The product approach (or “product-oriented LCA”)**, which focuses on a specific life cycle. This type of approach takes into account product-specific rates for recycling and recovery and considers, when allocating material and energy recovery impacts and benefits, 2 to 3 life cycles (product-based life cycles): the analysed life cycle and the previous and/or next life cycles. These are calculated for a functional unit relating to the analysed product.
- **The waste treatment approach (or “waste-oriented LCA”)**, which focuses on the impacts and benefits of waste treatment processes. The typical reference unit is the mass or volume of waste entering the waste management system.

Since the focus of waste-oriented LCAs is on the treatment of waste as such, these approaches do not have a multi-cycle life allocation logic, so the study only focused on the “material” and “product” approaches. The following methods have been analysed in this study (the reader will refer to the final report for this analysis):

- Example of a “material approach”: the multi-recycling approach (MRA), which allocates over all the life cycles of products in which the material in question is used.
- Example of a “product approach”: the Circular Footprint Formula (CFF), which allocates over 3 life cycles (current / analysed, previous and next).

Multi-cycle life allocation: conclusions and recommendations

Different consequences of multi-cycle life allocations have been identified. The following general recommendations can be given:

- Ensure that impacts and benefits over several life cycles reflect the specific contributions to the products, i.e. the “polluter pays” principle is fully applied.
- When benefits are allocated to recycling, energy recovery and component reuse, they must be balanced by similar flows for the use of these secondary materials, energy and components in a product.
- Avoid allocating to more than three life cycles, that is, more than the life cycle analysed, the previous life cycle and the next life cycle, for two reasons: 1/ losing the connection between the product systems greatly increases the uncertainty of the analysis (especially for products with a longer life), and 2/ the specificities of the products in which the material is used (inclusion rate of recycled products, recyclability, sortability, etc.) cannot be taken into account.
- For studies of products with a long lifetime (such as buildings), uncertainties around the data used for end-of-life recycling/recovery must be taken into account.
- Ensure all forms of end-of-life recovery (i.e. recycling of materials, energy recovery, reuse of compounds) are explicitly considered in the same way.
- Ensure the chosen approach is compatible with the consequential or attributional approach used.

In-depth study B: Taking into account the actual “residual value” of waste

In an earlier phase of the study, we carried out a detailed analysis of the approach proposed by Bleu Safran as part of the study carried out for the ADEME and Eco-Emballages on the environmental assessment of sorting and recycling plastic household packaging other than bottles and containers (May 2014)¹ to better reflect the residual value of waste (in terms of energy content). To improve the assessment and comparison of the energy performance of waste treatment systems, the authors suggest that the energy contained in the waste is taken into account when quantifying the total primary energy consumption.

As part of this in-depth assessment, the possible extension of the method to other indicators or environmental issues, primarily the use of resources was of particular interest. We wanted to investigate the possibility of relying on indicators of depletion of available resources in an LCA to assess the residual value in terms of waste resources. By analogy with what is suggested for the primary energy consumption indicator, this could be done for example by calculating a resource indicator equivalent for the waste stream considered.

In the following two paragraphs, we:

- Recall some of the key questions and limitations when developing resource LCA indicators;
- Examine the specificities that may arise when estimating the residual value of waste as a resource.

Before that, it is important to note that the aim of the LCA resource indicators is to take into account the **declining availability of resource-based functions for future generations** (definition of the resource protection area), adopting a vision related to the functional value of resources, as opposed to their intrinsic value (see the SCORELCA report on indicators of resource depletion in LCAs²).

¹ Ademe, Eco-emballages. Environmental assessment of the project to extend waste sorting instructions to all plastic household packaging - final report following a critical review, 2014

² SCORELCA - Indicators of resource depletion in a Life Cycle Analysis. BIO Intelligence Service, September 2013.

Issues and general limitations of the resource indicators used in LCAs

One of the first limitations of resource indicators used in LCAs is due to the fact that the methods use the same indicator to assess resources that do not have the same functions: i.e., a unique reference system is used to account for qualities/skills that should be assessed against different standards (their expected uses or functions).

A second limitation to the resource indicators used in LCAs is due to the fact that the methods do not really distinguish a destructive resource consumption from a “simple” immobilisation of these resources. These two types of action are considered similar for the assessment. Most resource depletion indicators assess a *potential* depletion of resources.

Specific issues when categorising a (waste) resource

When assessing what a resource is and how to identify the different resource categories when this is applied to waste and no longer to resources taken from the environment, this raises specific questions because of the anthropogenic nature of waste, as opposed to “natural” resources taken from the environment. The specific questions that arise when trying to assess the value of a waste as a resource are as follows:

- Should the assessment be carried out using the same classification and reference system as those used to assess “natural” resources? As such, plastics and alloys, for example, are not part of this matrix and have no value/function of their own; bronze, for example, is then assessed through a reading of its copper and tin content.
- Should the assessment be carried out by adapting and extending the classification and reference system used to assess “natural” resources? As such, plastics and alloys would have their own place and characterisation factors.

Conclusions

In view of all the above, it seems that extending the method to a resource depletion indicator *using currently available resource depletion indicators* is potentially complex.

The Impact World+ method for resources, however, appears to be a promising way. On the one hand, it translates the functions of each resource by integrating the notion of user sectors into the model and, on the other hand, it takes into account how the resources are used, separating the actual depletion of the resource and its competitive use: only the fraction actually dissipated will be taken into account, and not the full extracted resource stream. The method which takes recycling into account as a new availability of the functions of a resource may perhaps be used to assess the value of waste in terms of resources (which may be lost if the waste is landfilled or incinerated, or used when the waste is recycled).