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The Life Cycle of Biodegradable and Compostable Packaging from the Perspective of Developing a Sustainable Bioeconomy

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Abstract

This paper aims to present a study linked with the evaluation of the life cycle of both biodegradable and compostable packaging focusing on the impact these have upon the environment, regardless of the life-cycle stage, actually looking at it as a whole. In this article, the evaluation process will focus on the final stage of the product's life - decommissioning and reintegration into the environment.

At present, in order for products to be approved by consumers, who are increasingly selective about health and environmental protection, they need to send an appropriate message. The message for consumers can take different forms, being informed about: rational use of resources in the production process, economical and sustainable packaging, attestation of the quality of the product in question, the fact that they are sustainable (compared to similar products in trade). The explosive development of design technologies and software allows the identification of design solutions that lead to the optimization of the project in a new, clean, environmentally friendly formula. Eco-design must ensure technical and aesthetic accuracy, while identifying the optimal shape depending on the chosen material. Consumers are particularly concerned about its persistence in the environment, due to the decomposition time of 100 to 400 years (Zins Beauchesne et al., 2008), its non-renewable fossil resources and the amount of waste allocated to it. The presence of dispersed plastics in nature associated with their persistence in the environment causes major impacts on terrestrial and marine ecosystems (Allsopp et al., 2006).

In this context, the objectives of this article are risk assessment, environmental performance assessment, environmental impact assessment and identification of possible changes in each phase of the life cycle of both biodegradable as well as compostable packaging, which in turn may be the originator source of environmental benefits.

Keywords: *life cycle, biodegradable and compostable packaging, sustainable bioeconomy.*

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1. Introduction

According to the standard ISO 14040 (2006) Environmental management. Life cycle assessment. Principles and framework, the life cycle means “the consecutive and interrelated stages of a product-system, from the acquisition of raw materials or the generation of natural resources to post-use”. A product system is defined as the total system of both unitary as well as elementary processes that are involved in the life cycle of a product. The term "unitary process" refers to any activity that produces an output with economic value, or that provides a service with economic value. The term "product" is considered in the broadest sense - including physical goods and services, both at operational and strategic levels.

A life cycle definition that describes in detail all the successive phases of the product's “life” is as follows: “The life cycle includes the phases: conceptualization, project idea development, engineering study, process planning, manufacturing, operation, maintenance (repair) and withdrawal”.

2. Problem Statement

The life cycle of a product has as a starting stage the preprocessing of materials into semi-finished by-products or primary materials, continues by processing them into components and then by assembly and packaging as a final product. Following the sale, the product enters the use stage in order to satisfy the consumers' requirements. The last stage of decommissioning involves operations of processing the used product by reuse, recycling, remanufacturing, waste processing, etc. (Red, 2013).

The life cycle engineering of a product or process has the role of optimizing the life cycle stages, together aiming to balance the gains and losses related to energy, materials, packaging, chemical, biological and waste processing. There are several directions of ecological efficiency:

- reduction of material consumption,
- reduction of energy consumption,
- reduction of toxic materials,
- increasing the recyclability of materials,
- development of renewable resources,
- increasing the sustainability of products and services.

Product life cycle assessment (LCA) is a technique environmental management which identifies the flows of materials, energy and waste of a product during a product life cycle and their impact on the environment.

The environmental encyclopedic dictionary (Pârvu, 2005) presents a developed and comprehensive definition: "The evaluation of the life cycle of a product represents the evaluation and analysis of the consequences of the product's action on the environment; the evaluation follows the product from the extraction and processing of raw material, transport and distribution, use, profitability, maintenance and recycling, until the final storage or until its reintegration into the environment. "

As defined, LCA - "Life Cycle Assessment" refers only to the environmental impacts of the product-system and does not address financial, political, social factors, etc. (eg cost impacts). This life cycle is sometimes called "from cradle to grave". When hearing about "cradle-to-grave" it refers to the life cycle of a product taking into account as starting point the moment when the product is being designed and following through all the next steps: acquisition as well as usage of raw materials and even more actionable moments such as manufacturing and processing taking into account the waste, storage, distribution, use and disposal from use or recycling.

Life cycle assessment (LCA) is a tool that is used to assess various environmental aspects as well as potential effects of products, processes or activities that interact with the environment with the sole purpose of defining areas of improvement. In fact LCA looks over the entire life-cycle of either a product or a certain type of activity, overviewing also steps such as the extraction and processing step of raw materials, production processes, transport and distribution, use/reuse and maintenance of products, recycling and disposal (Ionescu et al., 2008).

ACL involves the following steps:

- Establishing the scope of the LCA, the methodology and the restrictions (such as resources, quality and volume of data);

- Drawing up an inventory of the inputs and outputs of a system (quantification of energy, raw materials used and waste discharged into the environment) and their evaluation;

- Identification and evaluation of the potential effects generated by the respective inputs and outputs on the environment (the effects resulting from usage of resources or the impact and influence upon humanity's quality of health as well as elements: air, water and land quality and on ecosystems are taken into account);

- The reading of the results gathered through the inventory stages and evaluation of the effects through the prism of the study objectives (Dubina et al., 2010).

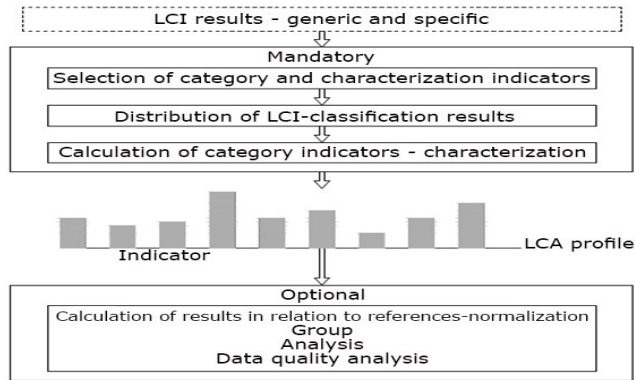


Figure 1. Illustration of the actions performed in the evaluation of a life cycle;
Source: ISO 14042 (2007)

3. Research Questions / Aims of the research

This article presents the impact of a product on the environment that must be evaluated during all stages of the life cycle. There are products that consume significant resources, others less or not at all. Designers need to know the share of consumption at each stage of the total estimated for the entire life cycle. For this they have at hand specific tools, such as LCA. The results of such analyzes can be applied to new products from the conceptual design phase of the design process. The proposed new solutions are evaluated according to criteria that include the environmental impact. In the process of assessing the impact of a product on the environment, designers tend to focus on obtaining raw materials, manufacturing and the stage when the product is in use, giving less importance to the post-use period. There is also another category of products, which have a reduced impact on the environment while in use, but indirectly cause a major impact throughout the life cycle (Bârsan & Bârsan, 2010).

In the case of a company, reducing expenses and gaining some credibility in the market are the main "pro" arguments for implementing the solutions indicated by LCA. Here are what these measures might be:

- the design of the product and its packaging taking into account the possibility of using inexhaustible, recycled or recyclable resources;
- choosing the suppliers of raw materials taking into account the impact that each material or component used in the production process can have on the environment;
- a better assessment of environmental risks during the production or use of a good;

- providing life extension solutions (by reuse or recycling);
- establishing hierarchies in resource and waste management.

Recent research has attempted to introduce social aspects into the study of the life cycle, as well as their relationship with the state of the environment. According to British researchers, the Social and Environmental Life Cycle Assessment (SELCA) allows us to understand how human activities contribute to changing ecosystems and vice versa, as well as reflecting on social life, the impacts on the environment. A complex tool such as SELCA, can facilitate the identification of factors involved in strategic planning decisions for a society with a sustainable bioeconomy, provided that the development of methodologies and evaluation models not only quantitative but also qualitative. The environment is a very complex system that can be studied only with the help of tailor-made models.

4. Research Methods

A significant number of methodologies as well as databases and tools are available and below we will list a selection of them:

Methodologies for assessing the impact on the environment in the product life cycle:

- Eco-Indicator 99 - is a loss-oriented method. It is the basis for calculating eco-indicators for materials and products.

One of the most common methodologies CML 2001 and it's grouping the results in mid-point categories taking into account common mechanism or largely accepted and adopted groups, such methodologies are available online such as:

- The one provided by the Faculty of Science of Leide University (n.d.)

- Life-cycle assessment center (LCA center, n.d.)

Databases for product life cycle assessment:

- ProBas (n.d.) which is a database with life cycle information for a large number of processes and materials being a process-oriented basic data information

- EcoInvent - The EcoInvent database was developed by the Swiss Lifecycle Inventory Center (n.d.)

- Association of Plastics Manufacturers (APME) has already began to map and record numerous ecological profiles basic chemicals and plastics.

Life cycle assessment tools:

- eVerDEE - This life cycle assessment tool for SMEs is an adaptation of ISO 14040 requirements aiming to provide ready-to-use functions linked back to a solid and trusted scientific base.

- EUP EcoReport – As an integrated part of "EuP eco-design methodology" project, a new tool emerged aiming to assess the life-cycle of products that consume energy.

- GaBi - The GaBi business program is a tool for conducting life cycle assessments using life cycle modeling data. In addition to evaluating the product life cycle, the GaBi program assists the user with the following:

- greenhouse accounting
- life cycle engineering
- ecodesign
- studies for the efficient use of energy
- material flow analysis
- environmental assessments
- environmental and sustainable development reports
- risk management – based on strategy
- assessment of overall costs

GaBi contains a large set of databases that enables accuracy of data available at <http://www.gabi-software.com>

- Sima Pro is a program that helps improve LCA policy

An ACL study consists of:

- defining the purpose and scope of the study;
- issuing a life cycle model of a product, with all its influences on the environment;
- understanding the impact on the environment;
- interpretation of the study.

In the Sima Pro program, each section is able to describe the purpose and location of each element, so that in the end the impact of a product on the environment can be interpreted. Interpretation is the life cycle assessment phase where both finding from inventory analysis as well as the assessment upon the impact are being put together with the sole purpose of reaching a complete set of conclusions and generate structured and documented recommendations. An analysis of the major contributions is performed, an analysis of sensitivity and uncertainty that may lead to conclusions on the satisfaction of the purpose and objectives of the LCA study. Therefore the results of the analysis and interpretation may lead to a form of well-rounded recommendations, regarding the areas in which action will have to be taken as a matter of priority, in order to prevent ecological consequences and harm to human health. Typically, this phase will generate decisions or an action plan.

The sensitivity analysis aims to validate the reliability of the final results, by determining the influence of the variation of the hypotheses, the source data and the methodology.

The uncertainty analysis aims to verify the influence of the uncertainty of the main data on the results of the models. This analysis is usually done with computer tools, using for example Monte Carlo method.

For LCA diagnostic studies, data are used to identify critical segments of the life cycle that contribute disproportionately to the overall impact of the system on the environment. In the case of comparative ACLs, the life cycles of competing systems that perform the same function are ordered based on environmental performance and then the optimal alternative is selected.

5. Findings

Table 1- Applications of life cycle analysis

LCA applications	Examples in the field of food packaging
Help with the decision to choose a process	Promoting PLA recycling or composting
Decision support for optimizing existing processes after identifying weaknesses	Optimization of water consumption for the production of PLA resin granules
Decision on the design of new products or services	Eco-design of food packaging
Decision on the organization of operations	Choice of transport modes for packaging distribution
Decision on the effectiveness of a regulation	Prohibition of original single-use fossil plastic bags or not?
Decision to guide public policies	Subsidies for bio-based bioplastics or rather compostable bioplastics?

Several LCA studies on different types of food packaging are listed in the literature, but it is often difficult to compare them because the systems studied vary. The choice of the framework for the analysis, the definition of the system limits, the functional unit, the geographical and industrial context, as well as the choice of the impact assessment method are among the differences that complicate the comparison of the results (Pralea et al., 2007). Overcoming these difficulties by standardizing the methodology and bringing coherence between studies is one of the advantages. Functional

unity, system boundaries and types of environmental impact are among the points defined by the document to standardize the methodology. As regards the limits of the packaging life cycle system,

We will analyze an example of ACL for biodegradable and compostable packaging (British Standard, 2006).

This LCA study coming up next aims to compare biodegradable and compostable food packaging to other packaging options that are still created using recycled materials or some that are manufactured using regular plastics of fossil origin. The choice was not randomized, but actually it was done as a result of various conclusions that look at the performance of both biodegradable and compostable packaging aiming to review the productivity.

LCA of NatureWorks PLA Ingeo packaging compared to PET for food packaging was developed by the Institute for Energy and Environmental Research (IFEU) in Germany, an independent center of excellence in the field of environment, with more than 30 years of experience (Krüger et al., 2009).

NatureWorks' Ingeo PLA packaging has been compared to fossil plastic packaging, namely polypropylene (PP), polystyrene (PS) and polyethylene terephthalate (PET).

The objective of the study was to compare the environmental performance of the same type of PLA packaging with virgin and recycled PET containers. The functional unit is 1,000 units of 500 ml of packaging used to contain cold foods, for example salad.

Regarding the scenarios, among the studied cases are the following packaging weights: 15 and 19.9 g for PLA and 19.9 g for PET. The 15 g PLA container is considered comparable to the 19.9 g PET container, because the PLA stiffness is higher and its density is lower. Improvements to the PLA manufacturing process have been considered.

For each scenario, the following environmental impact categories were assessed: fossil resources, climate change, summer smog (photochemical pollution), acidification, aquatic eutrophication, terrestrial eutrophication, human toxicity associated with carcinogenic effects, human toxicity associated with fine particles, land use and renewable and non-renewable energy consumption.

Some of the environmental impacts are shown in Figure 3, which illustrates how the results are compiled. According to legend, environmental impacts are classified according to their sources: plastic production (resin granules), transportation, packaging production and end-of-life treatment. With regard to recycled PET, the additional impacts that are taken into account are those related to the recycling process and the environmental tasks of the life cycle of virgin PET that has been recovered. In addition,

'Ingeo 5' on the graph's abscissa refers to PLA produced in accordance with the NatureWorks process, while 'Ingeo NGT' refers to PLA made according to the new fermentation technology.

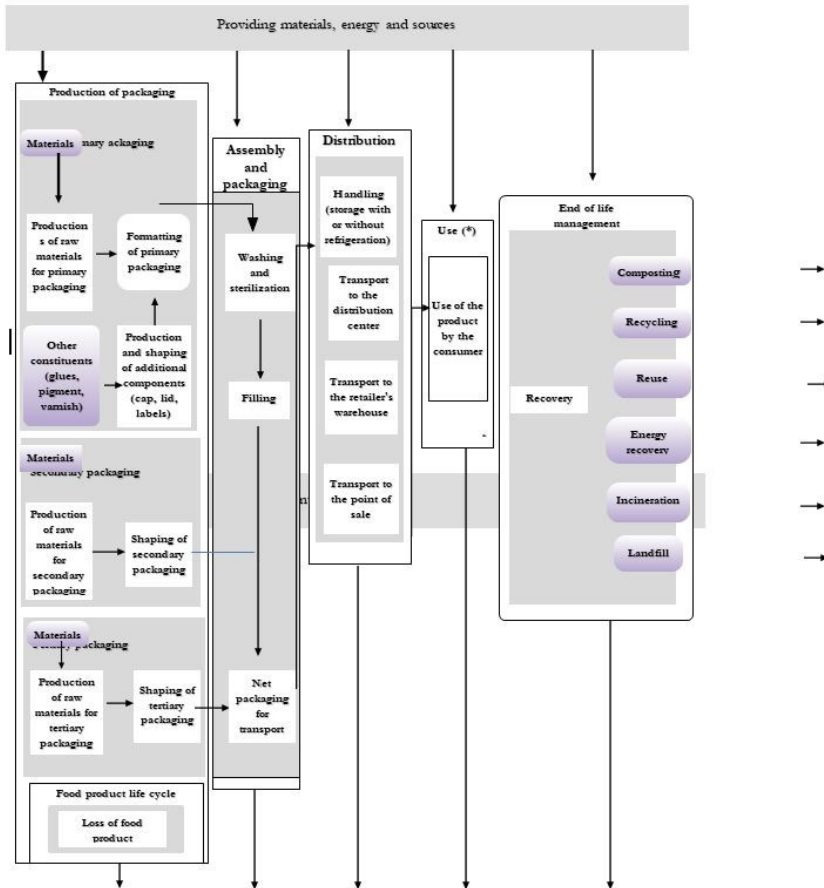


Figure 2. The boundaries of the life cycle
Source: Quantis (2011)

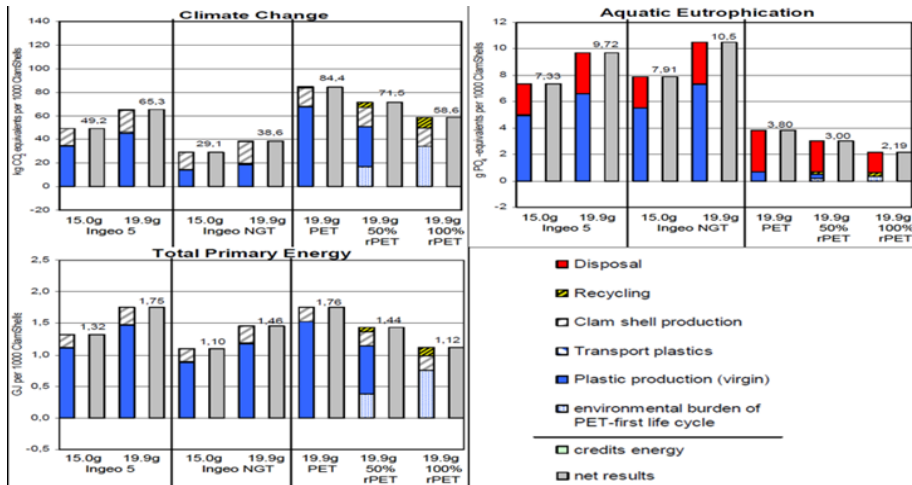


Figure 3. Environmental impact

Source: Krüger, et al. (2009)

Figure 3 is representative of the more general results of ACL, because for certain categories of environmental impact, biodegradable and compostable packaging (PLA) behaves better compared to PET containers, while sometimes it is the opposite (Krüger et al., 2009). For example, PLA packaging contributes less to climate change because CO₂ emissions are lower than all studied PET containers. On the other hand, LCA does not favor PLA in terms of aquatic eutrophication, because for all scenarios, the impact on the environment is greater than PET packaging. It is also interesting to note that the total energy used does not separate the two types of materials. 100% recycled PET uses 1.12 GJ per thousand units, while for PLA the best performance is 1 GJ.

In summary, table 2 compares the environmental performance of biodegradable and compostable packaging compared to traditional plastic packaging. Only the best option was chosen, ie 15 g PLA packaging made with a new fermentation technology and 19.9 g completely recycled PET packaging.

Table 2 Comparison of the environmental performance of PLA against PET.

Environmental indicators for which the type of material obtained the best environmental performance	
Biodegradable and compostable: PLA	Original plastic fossil: PET
<u>Scenario:</u> 15 g packaging and new fermentation technology	Scenario: 19.9 g packaging and 100% recycled
Use of fossil resources	acidified
Climate change	Aquatic eutrophication

Summer smog	Eutrophication of the Earth
Human toxicity associated with carcinogenic effects	Human toxicity associated with fine particles
Non-renewable energy consumption	

Another LCA study is the comparison of different trays manufactured by the Cascades company. This study was conducted by the Interuniversity Research Center for the Life Cycle of Products, Processes and Services (CIRAIG), which is a life cycle expertise center based at Polytechnique Montréal. Cascades commissioned CIRAIG to perform a comparative life cycle analysis of different food packaging containers. Fifteen environmental impacts were assessed, grouped into the following five categories: human health, ecosystems, climate change, resource depletion, aquatic acidification and aquatic eutrophication. The summary of results is presented in Table 3. The results are reported in relation to the material with the highest impact in each category (100%) (Belley, 2011).

Table 3 The relative environmental impact of food packaging *Source: Belley (2011)*

	XPS	OPS	PET	RPET	PLA	PP	MP
Human health	13%	32%	85%	48%	100%	62%	7%
Ecosystems	5%	15%	26%	20%	100%	29%	10%
Climate change	26%	72%	85%	65%	100%	88%	34%
Resource depletion	33%	82%	100%	72%	87%	84%	27%
Aquatic acidification	19%	44%	52%	39%	100%	90%	10%
Aquatic eutrophication	18%	2.3%	59%	38%	100%	71%	26%

6. Conclusions

The LCA results presented above are interesting from several points of view. The processes that generate the greatest impact for almost all indicators are the stages of raw material production and packaging manufacturing. The literature review included in the LCA guidelines developed by Quantis reveals the same observation: "the stage of production and packaging of food containers is generally the stage with the most important contribution for most impact categories". Weights are essential and will greatly influence the resulting environmental performance. For NatureWorks' PLA, a reduction of approximately 25% in the weight of the container significantly reduces the environmental impact for all indicators.

The same is true for CIRAIG - LCA performed for Cascades food packaging, because for several of the indicators, the lowest environmental impacts are associated with the least heavy container, made of expanded polystyrene (Belley, 2011).

The study specifies that certain properties may not be equivalent, including water resistance or stiffness. This difference has an impact on the maneuvering space that can be used to determine the characteristics of the products in different scenarios, for example, the weight of the containers.

Another major point that distinguishes the two studies refers to the environmental performance of biodegradable and compostable packaging (PLA). The CIRAIG study for Cascades products identifies PLA as the worst environmental choice, because compared to other materials, the potential environmental impact is the highest for five categories of indicators out of six. At the level of the IFEU study on NatureWorks PLA, the environmental performance between PLA and PET packaging is much more divided. These IFEU results show that it is generally difficult to compare different options or products. A product can demonstrate advantages over some potential impacts and disadvantages over others.

It would have been interesting to take into account additional scenarios or indicators. For example, in the case of the IFEU ACL, disposal in landfills is the only end-of-life treatment method that has been considered for the United States. The evaluation of the disposal of PLA packaging by compost would have allowed the analysis of the impact of this processing method on the various indicators. On the other hand, the addition of water resources as an additional indicator would have been of interest for the two studies. PLA production requires water consumption in the manufacturing process and in the cultivation of corn, which is its raw material. One study reports that this consumption is competitive with that of traditional fossil plastics, but the comparison would have been interesting for all scenarios.

Finally, this chapter demonstrates all the complexity related not only to performing an ACL, but also to analyzing and interpreting the results. Despite the existence of ISO standards, the degree of freedom associated with the development of an ACL remains significant. Authors have to make many choices and assumptions, and collecting reliable data is often complex. It is important to consider the limitations and partially subjective nature of ACL. Moreover, European Bioplastic considers that LCA is a good tool for assessing the environmental performance of a product, but that it is too complex to serve as a communication tool for consumers. In short, it is an excellent method of analysis and optimization for manufacturers.

Because ACL considers the entire life cycle The results of the study will only be applicable to the products or processes analyzed. For example,

the type of raw materials, the manufacturing technology, the modes of transport, the chosen functional unit and the end-of-life treatments are some examples of the unique characteristics of the studied system. Therefore, no generalizations are possible regarding the best environmental performance of one group of products compared to another, biodegradable and compostable versus traditional plastics.

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