LCA methodology applied to the realization of a domestic plate: confrontation among the use of three different raw materials

M. Bevilacqua*, F.E. Ciarapica*, L. Postacchini, T. Castagna***

**Dipartimento di Ingegneria Industriale e Scienze Matematiche, Università Politecnica delle Marche, 60131, Ancona, Italy (m.bevilacqua@univpm.it; f.ciarapica@univpm.it; tompson88@hotmail.it)*

***Faculty of Science and Technology, Free University of Bozen, piazza Università 5, Bolzano, Italy (leonardo.postacchini@natec.unibz.it)*

Abstract

Purpose
This paper aims at assessing the environmental impact of a household product such as a domestic plate, comparing, by the use of the LCA (Life Cycle Assessment) methodology, three different materials in which it can be made: plastic (polypropylene), ceramics and MaterBi (biodegradable plastic). To better understand all stages of the life cycle of each type of plate, each study has been divided into three parts: manufacture, use and disposal. These three phases join in a single project for each type of plate, in order to compare the environmental final impacts of the three life cycles, but also to be able to go back to the intermediate stages. The study will focus on the comparison of the environmental impacts of the different types of dish, analyzing the results of the LCA, their accuracy, and, at the same time, identifying the critical stages, the time and resources necessary for the implementation of this methodology.

Design/methodology/approach
The Life Cycle Assessment (LCA), or the evaluation of the life cycle of a product, is a methodology for assessing the environmental impact of a product, or service, throughout its life cycle (European Commission et al., 2010; ISO, 2006a; ISO, 2006b)). The development of the study required the knowledge of the software OpenLCA, on which the entire project has been developed. OpenLCA is a free software, with a wide range of features and available databases, created by "Delta Green" in 2006. It is an open source software, so with the source code freely available. Thanks to its flexibility and wide range of data, this software can be used in different fields of application.

Originality/value
The study responds to the new needs of the market that requires more and more attention to environmental issues (Bevilacqua et al., 2010; Kjaerheim, 2005). For the enterprises, eco-innovation of the products will become even more a required field of intervention, and, at the same time, an opportunity to innovate their products and win new market share (Pardo et al., 2012; Saarinen et al., 2012; Zufia et al., 2008). It is in this context that the European Union is promoting European policies for sustainability, in particular through the Integrated Product Policy (IPP), aimed at developing a new generation of "green" products and services. The LCA is a methodology that underlying systems and tools such as environmental labels and standardized by ISO 14020 declarations (Ecolabel, self-declarations, EPD), the environmental management systems (EMAS, ISO 14000, POEMS), and the Life Cycle Costing (based on the same approach of LCA, but using economic flows). Therefore the benefits from the application of an LCA are not only environmental but also economic and commercial.

Keywords: Life Cycle Assessment, domestic plate, plastic, ceramic, biodegradable plastic, OpenLca

1. Materials and Methods

1.1 Goal and scope
The goal of this study is to evaluate the environmental impact of a domestic plate, comparing three different materials in which it can be made: plastic (polypropylene), ceramic and Mater-Bi (biodegradable plastic).

1.2 Functional Unit
As functional unit, the single dish has been selected. The plastic plate is made of polypropylene (PP), a completely recyclable material for at least 3 times, and it weighs, on average, 0.03 Kg. The ceramic plate is made of a simple terracotta, and it weighs on average 0.5 Kg. The dish in Mater-bi is made of vegetable components, and it is a plate perfectly biodegradable

and compostable. It weighs a little more than a plastic plate: 0.04 Kg.

1.3 System Boundaries

The system boundaries, of an LCA study, are crucial in determining the final results, since they define the processes to be included or excluded from the analysis. It has been supposed that the company has its manufacturing plant in Recanati (Italy), and that it produces, in this plant, the three types of plate, purchasing raw materials from other companies on the Italian territory. In particular, we analyze now the system boundaries for the different types of dish.

1.3.1 System Boundaries for the Plastic Plate

For the plastic plate, the system boundaries extend from the manufacturing firm of Bergamo, where it is produced the raw material (polypropylene), until the end-life of the plate, in the incinerators of Bologna. Within these boundaries are included: the transport of the raw material from Bergamo to Recanati (480 km); all stages of production of the plate; the transportation of the finished product to the retailer in Bologna (250 km); the use by the consumer in 3 years, and the end-life in the incinerator. The life cycle of the plastic plate is represented in Figure 1:

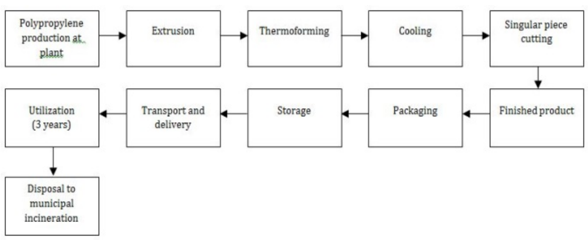

Figure 1 - *Life Cycle of the Plastic Plate*

In this analysis, it has been chosen to neglect the production phases of cooling and cutting, due to the difficulty in obtaining accurate data, and the lack of relevance of their impacts on the project. The majority of the data has been entered directly from the database EcoInvent, while some data have been assumed, such as the use of electricity for the production of the plate. It has been assumed that the consumer uses 2 plastic plates per day, for 3 years, for a total of 2190 dishes.

1.3.2 System Boundaries for the Ceramic Plate

For the ceramic plate, the system boundaries extend from the raw material manufacturer in Sassuolo (MO), to the landfill near Bologna. Within these boundaries are included: the transport from Sassuolo to Recanati (290 km) and from Recanati to Bologna (250 km); all the production stages of the plate; the use by the consumer, in three years; the end-life.
The life cycle of the ceramic plate is represented in Figure 2:

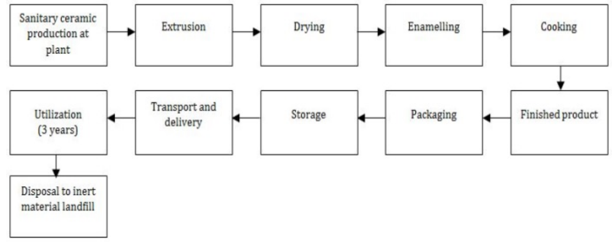

Figure 2 - *Life Cycle of the Ceramic Plate*

Assumptions have been made about the total consumption of electricity, for production, and the energy consumption of the cooking and drying kilns. It has been chosen one single stage of cooking, and to neglect the enamelling phase, which has been considered of little importance for the study. It has been assumed a use of the single plate 2 times a day. The consumer uses only one dish for all the 3 years, not throwing it after every meal, but washing it with tap water and liquid soap. It has been assumed, for each wash, a use of 0.25 l of water, for a total of 547.5 l for 3 years, and, regarding the liquid soap, a use of 0.00025 kg for each wash, for a total of 0.5475 kg for 3 years (data obtained from direct experimentation).

1.3.3 System Boundaries for the Mater-Bi Plate

Mater-Bi is an innovative family of bioplastics that uses vegetable components such as corn starch, and polymers that have been obtained either from renewable raw materials, or from raw materials of fossil origin. In this study it has been chosen the corn starch, which is the most used by the company of Terni, where it is purchased. For the plate in Mater-Bi, the system boundaries extend from the manufacturing firm of Terni, where is produced the raw materials, to composting plants. Even in this case, it has been included: the transport of Mater-Bi from Terni to the plant in Recanati (165 km) and from Recanati to the retailer in Bologna (250 km); all the production phases; the use by the consumer in 3 years; the end-life in composting plants. Mater-Bi can be processed according to the most common plastics processing technologies, to create products with features comparable to traditional plastics. The life cycle of the Mater-Bi plate is represented in Figure 3:

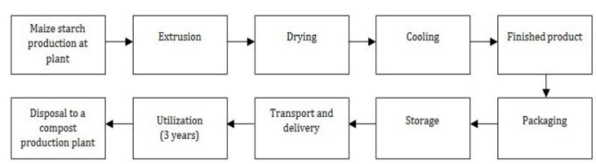

Figure 3 - *Life Cycle of the Mater-Bi Plate*

Even for the dish in Mater-Bi, as well as for the plastic, it has been neglected the cooling phase. It has been assumed the same energy consumption for the production of the plastic plate, considering that the process steps are similar. Even here, the consumer uses 2 dishes per day for 3 years, for a total of 2190 dishes. At the end of the life cycle, the plate will end up in composting plants, which use the biodegradability of the starting organic materials, to turn them into a final product called compost.

2. Results

Table 1 shows the value of the results, for each Life Cycle Impact Assessment category that has been taken into account in this study.

LCIA Category	Plastic Plate	Ceramic Plate	Mater-Bi Plate	Unit
	amount	amount	amount	
acidification potential - average European	0,40978921	0,024458164	**0,566068278**	kg SO2-Eq
climate change - GWP 20a	**167,5374783**	7,030556934	111,5573818	kg CO2-Eq
eutrophication potential - average European	0,261561572	0,015905215	**1,213917917**	kg NOx-Eq
freshwater aquatic ecotoxicity - FAETP 20a	1,511647072	0,890106442	**25,00785183**	kg 1,4-DCB-Eq
human toxicity - HTP 20a	0,649896947	1,265490476	**33,7743282**	kg 1,4-DCB-Eq
marine aquatic ecotoxicity - MAETP 20a	0,709514182	0,292094164	**6,975032046**	kg 1,4-DCB-Eq
photochemical oxidation (summer smog) - high NOx POCP	**0,027728679**	0,002257054	0,008729816	kg ethylene-Eq
resources - depletion of abiotic resources	**2,134844475**	0,062027784	0,543302551	kg antimony-Eq
stratospheric ozone depletion - ODP 20a	7,46E-08	4,42E-07	**9,99E-06**	kg CFC-11-Eq
terrestrial ecotoxicity - TAETP 20a	0,000134245	0,247145878	**0,259661867**	kg 1,4-DCB-Eq

Table 1 - *Results*

3. Discussion

For each impact category, in the following (Figure 4 – 8), we report the graphs with the percentage comparison of the product systems, for the three types of plate.

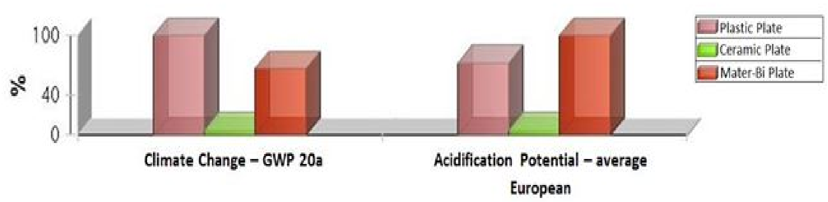

Figure 4 – *Comparison of the Characterizations (CML2001)*

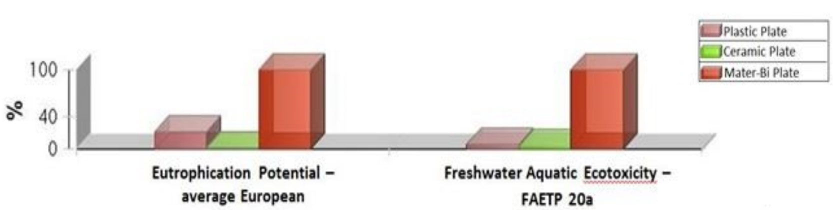

Figure 5 - *Comparison of the Characterizations (CML2001)*

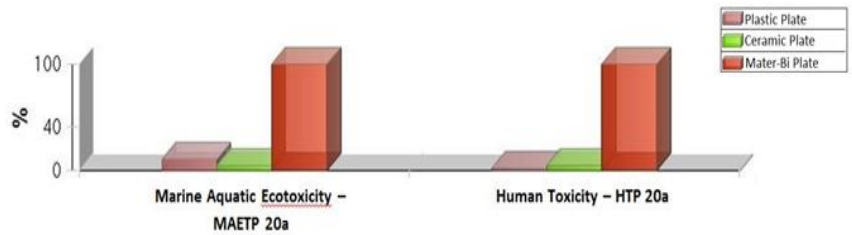

Figure 6 - *Comparison of the Characterizations (CML2001)*

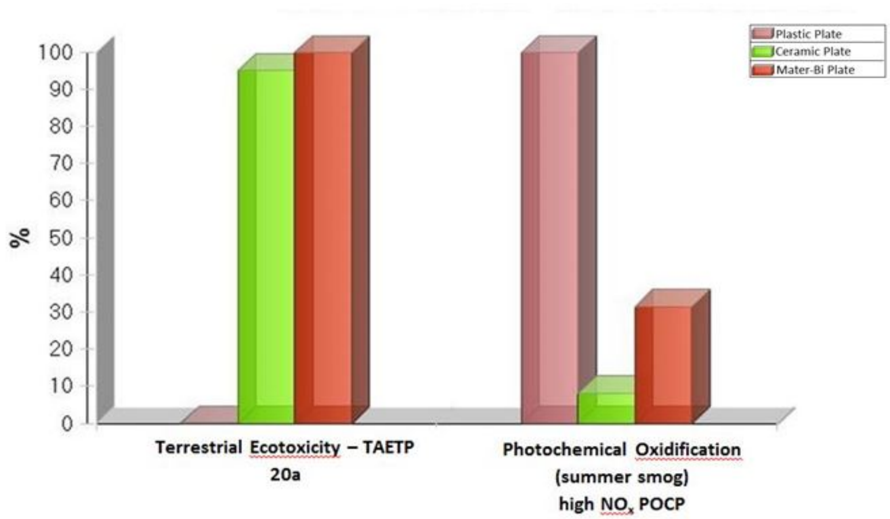

Figure 7 - *Comparison of the Characterizations (CML2001)*

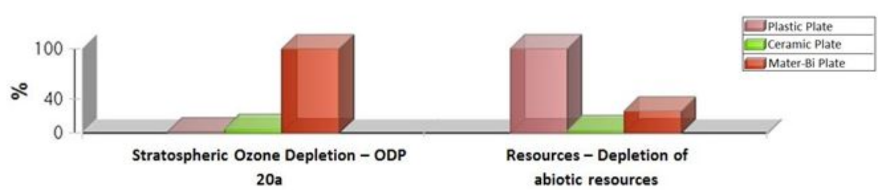

Figure 8 - *Comparison of the Characterizations (CML2001)*

Observing carefully at the graphs, extracted from OpenLCA, we can see how the Mater-Bi plate is much more impactful than the others. In fact, it is percentage higher than the others, in 7 out of 10 impact categories. Only with regard to climate change, formation of photo-oxidants and the depletion of abiotic resources, it turns out to be less harmful than the others. In these three categories, higher and more impactful is the plastic plate, while the ceramic plate has very negligible impacts. The latter is very harmful for only one category, the terrestrial ecotoxicity, due to the continuous use of liquid soap.

From these graphs, obtained from the comparison of the characterization of the three dishes, with the CML2001 method (Frischknecht et al., 2007), it results therefore more appropriate to use the ceramic plate,

while it is not advisable to use the one in Mater-Bi. This is because, the later recycling and composting are not sufficient to cover the enormous impacts, due mainly to the production of corn starch, which requires a very high utilization of resources.
The plastic plate has impacts relatively comparable to those of the ceramic plate, into 5 categories of impact (eutrophication, freshwater eco-toxicity, reduction of the stratospheric ozone layer, marine eco-toxicity and human toxicity). For the rest, it results significantly more damaging in acidification, climate change, formation of photo-oxidants and depletion of abiotic resources.

4. Conclusion

In this article, an assessment of environmental impacts through the LCA (Life Cycle Assessment) has been made. According to the study, the highest environmental damages are referable to the plates in Mater-Bi, followed by the plastic ones, while the lower loads are referable to the ceramic plates. The biodegradable dishes are presented to the consumer as the most friendly and sustainable for the environment, especially for the benefits due to composting. These positive aspects, however, are canceled at the very beginning of the life cycle of the plate, during the preparation of the raw material. In this study, it has been assumed the use of a plate of corn starch, and the environmental impacts, due to its preparation, are so high to nullify all the rest and to ensure that the biodegradable utensil is the most pollutant. Using another biodegradable material, or modify the processes of production of the raw material are the first improvements that should be made.
Plastic dishes, once opened, will inevitably become disposable products, which are used once and then disposed as waste. In the three years, taken into account in this study, the plates are used in number of 2190. This involves a huge amount of waste and a significant consumption of natural resources and emissions to the environment.
For the ceramic plate, the parameters, that are associated with the use, are essentially the consumption of tap water and liquid soap for washing. This means that, in the plastic dishes, those impacts which are caused by the use are much more dominant than those due to the production, while in the ceramic plates this gap thins.
In this study it has not been considered the possibility of recycling for the plastic plate. The recycling definitely strikes a blow for the plastic plate, but a more in-depth analysis should be carried out, with a longer period of time, in order to understand if this feature can mitigate some impacts, in the long run. The ceramic, instead, is disposed of in a landfill, since there is not, still now, a system of collection and recycling, but it is an inert material and the disposal of a single ceramic dish is never comparable to the amount of disposable plastic plate. The adoption of a reusable plate, therefore, requires a lower consumption of resources, which implies a lower environmental impact. The useful life of the ceramic plate has been considered of 3 years, certainly less than the average value, because this material has a high durability and the number of uses only depends on the breaking or the substitution by the consumer. The major impacts for the ceramic dish are recorded in the terrestrial ecotoxicity. From the characterization we saw that this impact is due largely to the use of the plate, that is the water and liquid soap consumption for washing. A possible improvement might be the use of a dishwasher, avoiding the waste of water and soap, but that would entail a greater energy consumption and other environmental loads. Minor impacts could be reached by changing production processes of the ceramic plate. Particularly critical is the packaging stage, so the use of high amounts of polyethylene. Other causes of impact, such as for the human toxicity and the depletion of abiotic resources, are the use of the ovens for cooking or, in the case of the reduction of the ozone layer, the preparation of the raw material.
Biodegradable and recyclable packaging is a possible solution to the problem of packaging and, of course, can be used for all the three dishes of this study. To limit the impacts due to cooking, we should use less polluting ovens or ovens which are fueled by renewable energy.
Other studies, however, should be made in this field. Different hypotheses, a longer period of analysis, and an extension of the system boundaries could change these results, in order to exclude the materials most impactful, and to concentrate the production and the use of those most ecologically sustainable.

References

Bevilacqua, M., Caresana, F., Comodi, G., Venella, P. (2010). **Life cycle assessment of a domestic cooker hood**. Journal of Cleaner Production, Volume 18, Issue 18, Pages 1822–1832.

European Commission, Joint Research Centre, Institute for Environment and Sustainability, 2010. **International Reference Life Cycle Data System (ILCD) Handbook, General guide for Life Cycle Assessment, Detailed guidance**. Publications Office of the European Union.

Frischknecht, R., Jungbluth, N., Althaus, H.J., Doka, G., Dones, R., Hischier, R., Hellweg, S., Humbert, S., Margni, M., Nemecek, T., Spielmann, M. (2007). **Implementation of Life Cycle Impact Assessment Methods: Data v2.0**. Ecoinvent report No. 3, Swiss centre for Life Cycle Inventories, Dübendorf, Switzerland.

ISO (2006a) ISO 14040:2006 **Environmental management - Life cycle assessment - Principles and framework.** International Standards Organization.

ISO (2006b) ISO 14044:2006 **Environmental management – life cycle assessment – requirements and guidelines.** International Standards Organization.

Kjaerheim, G. (2005). **Cleaner production and sustainability**. Journal of Cleaner Production, Volume 13, Issue 4, Pages 329–339.

Pardo, G., Zufia, J. (2012). **Life cycle assessment of food-preservation technologies.** Journal of Cleaner Production, Volume 28, Pages 198–207.

Saarinen, M., Kurppa, S., Virtanen, Y., Usva, K., Mäkelä, J., Nissinen, A. (2012). **Life cycle assessment approach to the impact of home-made, ready-to-eat and school lunches on climate and eutrophication**. Journal of Cleaner Production, Volume 28, Pages 177-186.

Zufia, J., Arana, L. (2008). **Life cycle assessment to eco-design food products: industrial cooked dish case study.** Journal of Cleaner Production, Volume 16, Issue 17, Pages 1915–1921.