Foamy polystyrene trays for fresh-meat packaging: A life-cycle inventory data collection and environmental impact assessment

Carlo Ingrao [a,e*], *Agata Lo Giudice* [b], *Jacopo Bacenetti* [c], *Amin Mousavi Khaneghah* [d], *Anderson de Souza Sant'Ana* [d], *Roberto Rana* [a], *Valentina Siracusa* [e]

[a] Department of Economics, University of Foggia, Largo Papa Giovanni Paolo II, 1, 71121 Foggia, Italy

[b] Department of Quality and Operations Management, Faculty of Engineering and the Built Environment, University of Johannesburg. APB Campus, P. O. Box 524, Auckland Park 2006, Johannesburg, South Africa

[c] Department of Agricultural and Environmental Sciences, Production, Landscape, Agroenergy, University of Milan, Via G. Celoria 2 - 20133 Milan, Italy

[d] University of Campinas, Faculty of Food Engineering, Department of Food Science, Campinas, São Paulo, Brazil

[e] Department of Industrial Engineering, University of Catania, Viale A. Doria 6, 95125 Catania, Italy

[*] Corresponding author: ing.carloingrao@gmail.com; carlo.ingrao@unifg.it

Abstract

Food packaging systems are designed to perform series of functions mainly aimed at containing and protecting foods during their shelf-lives. However, to perform those functions a package causes environmental impacts that affect food supply chains and that come from its life-cycle phases. Therefore, package design should be done based upon not only the issues of cost, food shelf-life and safety, as well as practicality, but also of environmental sustainability. For this purpose, Life Cycle Assessment (LCA) can be applied in the packaging field with the aim of highlighting environmental hotspots and improvement potentials, thus enabling more eco-friendly products. In this context, an LCA of foamy polystyrene (PS) trays used for fresh meat packaging was performed here. The study highlighted that the highest environmental impacts come from PS-granule production and electricity consumption. In this regard, the authors underscored that there are no margins for improvement in the production of the granules and in the transport of the material inputs involved as well as of the trays to users. On the contrary, changing the energy source into a renewable one (by installing, for instance, a wind power plant) would enable a 14% damage reduction. In this way, the authors documented that alternative ways can be found for global environmental improvement of the system analysed and so for enhanced environmental sustainability of food packaging systems.

Keywords: *Packaging system; Tray; Foam polystyrene; Life Cycle Assessment; Environmental hotspots; Wind power*

1. Introduction

During last decades, sustainable development has been one of the most popular and universal concerns; in another hand, the issue that future generation will be able to experience the same standards of living and opportunities for growth attracted lots of attentions (Accorsi et al., 2014a). In order to obtain goods with environmentally sustainable properties, application of Life-cycle Thinking (LCT) to design of them is essential. Thereby, consideration to their environmental impact along the whole life-cycle (from extraction of raw materials to product disposal at the end of use), in terms of human health, climate change, resources and ecosystem quality, is important. As Bauer et al. (2008) reported according to ISO 14040:2006 and 14044:2006 (International Organisation for Standardization (ISO), 2006a; International Organisation for Standardization (ISO), 2006b), Life-cycle Assessment (LCA) is a tool which substantiates LCT by a clear and structured methodology to estimate and assess the potential environmental impacts due to a product's life-cycle. In the ISO 14040:2006, "LCA is in fact defined as the compilation and evaluation of the inputs, outputs and of the potential environmental impacts due to a product-system throughout its life-cycle". As consequence of the LCT approach, the design of product should be adopted to possible evaluation of effects of product during using and also end-of-life. In another hand, LCA can be applied as a support tool for design and also to finding and assessing some technical solutions which can be used in the production process of product to minimise the impacts originated not only from the production itself but also from the phases of use and end-of-life.

As a systematic tool for identification and quantification of the environmental impacts associated with products' life-cycle, LCA has evolved significantly during the past three decades (Jeswani et al., 2010; Ingrao et al., 2015). Huge number of sectors such as automotive, buildings and construction, electronics, textile, agriculture, food production and packaging and so many others have used this methodology over the years (Madival et al., 2009). In particular, the role of packaging systems is highly important in the protection of food quality and shelf life, especially in the supply chain, since they are designed to allow consumers to obtain foods that correspond to their food quality and safety expectations (Accorsi et al., 2014b; Bertoluci et al., 2014). Packaging should provide the following objects: 1) food quality and freshness conservation; 2) correct identification of product; 3) convenience during storage and distribution (Meneses et al., 2012; Williams and Wikström, 2011). Other main functions are to display the brand image and to give information on the composition, preparation and traceability mode of stocking and end-of-life management (Bertoluci et al., 2014). In order to perform such functions, packaging causes environmental impacts that affect food supply chains (SCs) and, as a result, its life-cycle phases, namely production, transportation until consumption and disposal. Design of package usually is done based upon not only of the issues of cost, food shelf-life and safety, as well as practicality, but also of environmental sustainability (Leceta et al., 2013; Zampori and Dotelli, 2014). For this purpose, LCA can be applied with the aim of highlighting environmental hotspots in order to enable and promote more eco-friendly packaging systems, so positively affecting the life-cycle of foods. In particular, in the field of plastic trays and clamshells for both fresh and cooked food, several studies have been conducted over the years. By way of example, Madival et al. (2009) performed a cradle-to-cradle LCA of polylactic acid (PLA) in comparison with PET and PS thermoformed clamshell containers (for strawberry packaging) with emphasis upon different end-of-life strategies. Moreover, Díaz et al. (2010) did an evaluation of the effects of two packaging systems, such as vacuum pouch and plastic tray, on spoilage in a cook-chill pork-based dish kept under refrigeration. In addition, Kaisangsri et al. (2012) developed biodegradable foam trays from cassava starch blended through appropriately dosage and mixture of natural polymers of kraft fibre and chitosan. Results showed that foam produced from cassava starch by 30% kraft fibre and 4% chitosan revealed mechanical properties similar to PS foam.

The comparison performed by that team of authors could be extended also to the environmental perspective so as to highlight the less impacting system, thus enabling marketing of eco-friendly packaging products. For this purpose, LCA could be used as a comparative assessment tool, as already done by Roes and Patel (2011) to compare a sugar cane-bagasse food tray to food trays made from PET, PLA, and moulded pulp. Similarly, Suwanmanee et al. (2013) benchmarked the environmental impact of bio-based against petroleum-based plastics for single use boxes focussing attention upon PS, PLA, and PLA/starch.

As regards cooked food, the suitability of shallow aluminium trays for heating of different casseroles in microwave ovens in comparison with Crystalline Polyethylene Terephthalate (CPET) trays was studied by Ahvenainen and Heiniö (2006).

Therefore, it can be concluded that the field of plastic trays has been widely investigated, especially from a technological point of view, with the aim of evaluating their basic functions towards food content. Indeed, not so many studies dealt with plastic trays' life-cycle environmental assessment, in particular, for what concerns to foamy PS trays. From this point of view, a gap in the literature was observed, thus emphasising upon the need for more LCAs on this area to be performed.

In this regard, the present study discusses application of LCA to the life-cycle of foamy PS trays and so the authors believe that it could contribute to enhanced knowledge in the field by delivering reliable insights on data inventoried and results obtained. In particular the latter, as for similar studies, could be used for development of environmental assessments of packed-meat SCs, thus highlighting the importance of the study conducted.

2. Materials and methods

2.1 Methodological approach

To the ends of the study development, LCA was applied with the aim of assessing both environmental impacts and improvement potentials in the life-cycle of foamy PS trays for fresh meat packaging. This methodology was used because it enables addressing the environmental aspects of a product and their potential environmental impacts throughout its life-cycle (Guinée et al., 2011). The study was developed following the ISO standards 14040:2006 and 14044:2006 and, therefore, was divided into the phases of: 1) Goal and scope definition; 2) Life-cycle Inventory (LCI); 3) Life-cycle Impact Assessment (LCIA); 4) Life-cycle Interpretation (LCI). All data collected were loaded into the SimaPro v.7.3.3 (SimaPro, 2006), accessing the Ecoinvent databases (Ecoinvent, 2011) and then elaborated using the Impact 2002+ method (Jolliet et al., 2003) for LCIA development. As stated by Siracusa et al. (2014) referring to the ILCD-handbook (2010), Impact 2002+ allows for a feasible implementation of a combined midpoint/endpoint approach since it links LCI results via midpoint (impact) categories to endpoint (damage) categories. In this regard, Table 1 shows the distinction, provided by this method, between impact and damage categories. In particular, according to Joillet et al. (2003), the former represent the negative effects to the environment through which the damage (due to substances emitted and resources used) occurs, whilst the latter are obtained by grouping the impact categories into major ones and represent the environmental compartments suffering the damage. Furthermore, the method calculates non-renewable energy consumption and recognises carbon dioxide as the emitted substance with the greatest responsibility for the greenhouse effect and then for climate change. In this regard, it is underscored that, as clarified by Jolliet et al. (2003), Impact 2002+ is based upon the latest IPCC Global Warming Potentials (IPCC, 2001) with a 500-year time horizon, thus accounting for long term effects. In this regard, this author team believe that these aspects are fundamental to be considered, especially in the case of industrial processes such as the one object of the present environmental study. Finally, thanks to its set-up, the method appears to be more comprehensible for insiders and also more accessible compared to other methods.

Table 1
Damage and Impact categories (Impact 2002+)[1]

As regards the LCIA, this was carried out using both a mid-point and an end-point approach, and so the phases of normalisation and weighing were included in the assessment. The midpoint approach

[1] Source: extrapolated from Jolliet et al. (2003)

was used in order to express impacts by means of appropriate equivalent-indicators such as, for instance, $kgCO_2$ for Global Warming, $kgPM_{2.5}$ for Respiratory Inorganics and kgC_2H_3Cl for Carcinogens. Whilst, the endpoint approach was adopted because, in agreement with Ingrao et al. (2014), it allows researchers to present results with equivalent numerical parameters (points) and, in turn, to have environmental impacts quantitatively represented. Hence, according to Siracusa et al. (2014) damage and impact categories, processes and both substances emitted and resources used, could be easily compared to each other based upon the damage unit-point. The end-point approach enabled this author team to highlight the most impacting processes that so represent the system's hotspots and require priority attention when environmental improvements are planned.

Finally, to enable greater understanding of the study conducted, it is clarified that "total damage" stands for the damage associated to the life-cycle of 1 kg foamy PS trays. It can be calculated by summing up the contributions of the processes and materials included in the system boundaries or of the damage categories and of the impact categories or even of all substances emitted and resources used (Ingrao et al., 2014).

2.2 Goal and scope definition

This paper discusses application of attributional LCA in order to analyse inventory flows and environmental impacts associated with the life-cycle of trays made from foamy PS and generally utilised as the base of packaging for fresh meat. For the assessment development, the authors could benefit from the collaboration of a firm located in the North of Italy that was positively involved in allowing them to visit the production plant and in providing them all the needed primary data and technical information. In this way, the authors managed to create a model as-close-as-possible to reality and to perform a study of scientific value and reliability.

The study will make it possible to identify the most inventory processes and materials and to both qualify and quantify the environmental impacts due to the trays' life-cycle. For contrast, they could be divvied to: 1) the most impacting phases; 2) the most impacted damage categories; 3) the most impacting substances emitted and resources used; 4) the processes causing the emission and consumption of the above-mentioned substances and resources; 5) the most significant impact categories; 6) the environmental improvement potentials.

Finally, this team of authors believe that producers, technicians, LCA practitioners, researchers and policy makers will learn about both inventory data collected and results gathered. In this way, the study will support them in making decisions oriented to contributing to enhanced environmental sustainability of food supply chains. From this point of view, in agreement with Bare et al. (2000), the study could be of direct relevance for the producer to better understand both the environmental effects due to the manufacturing process and the improvement interventions needed. Therefore, the study carried out could support the producer to re-examine the merits not only of the tray production system but of the whole environmental company policy, in order to find ways for global improvement.

2.2.1 Functional unit and system boundaries

As established by the ISO 14044:2006, the "Goal and scope definition" phase includes definition of both Functional Unit (FU) and system boundaries. The FU was chosen in order to represent the reference for the link of inventory flows to environmental impacts and for comparability of results, whilst the system boundaries were defined so as to include all the most significant and pertaining processes related to the system analysed. In particular, the FU was identified with 1 kg of packed-trays delivered to food production and packaging firms, thus facilitating data collection and elaboration. However, according to the authors, doing so does not compromise usage of the created model for implementation of packed-food related assessments. In fact, the life-cycle of the trays investigated can be easily input to that of the food package based upon weight of the single tray utilised. In particular, the latter is equal to 8.98 g, whilst the maximum capacity amounts to almost 800 cm^3: in this regard, main dimensions of the single tray were provided by the producer and depicted in Fig. 1. This size of tray was chosen as the object of the present study because it is the most commercialised one amongst the other different types produced by the firm and so represents its core-business.

Fig. 1. Main dimensional characteristics of the analysed tray based upon information provided by the firm[2]

As per the system boundaries, these were defined so as to include the following subsystems (SS):

- SS1: preparation of the raw materials for the tray production;
- SS2: tray production;
- SS3: transportation to mass retailers (delivering phase);
- SS4: tray end-of-life.

It should be observed that transports to the tray manufacturing plant of the input materials concerning to SS1 were accounted for and modelled as part of SS2. In contrast, the use of the tray for fresh meat packaging was excluded from the system boundaries because it was considered by the authors as free from significant environmental impacts. This consideration was made because,

[2] Source: personal elaboration from the tray's image provided by the firm

as stated by Siracusa et al. (2014), once transported to users (mass retailers), such a package enters into the packed-food production as an input material at all effects: it is used as such, thereby accounting for the environmental impact associated with its life-cycle. Additionally, production of the food content was not taken into account, since it was considered by this author-team as outside of the aim and scope of the study: the study was, indeed, focussed upon the environmental assessment of an industrial process for production of food packaging trays. Furthermore, in agreement with Siracusa et al. (2014), the food production phase is outside of the system boundaries, because the analysed package can be for any type of fresh meat (cattle, pork and fowl), so making the model difficult to be implemented. In the light of this, considerations upon the waste generated by the expiry of the food product contained were not made, because they were considered by the authors as to be pertaining not to similar studies but to packed-food related assessments.

As regards the end-of-life phase (SS4), the latter occurs when the food contained is unpacked by the consumer and then the tray is thrown away into the domestic container of un-separated wastes. So, SS4 was modelled by the authors assuming that such post-use trays are disposed of in sanitary landfills, as generally established by local waste management systems. This is because the tray behaves like a sponge in the sense that one of its main functions is to absorb blood released from the fresh meat, thereby enabling reduced visual impact and, in turn, enhanced marketability. As a result, the tray is being contaminated with variety of microorganisms and so recycling is impracticable. Moreover, it should be observed that transport of the post-consumer trays (municipal waste collection phase) to the treatment plants involved in the development and management of their end-of-life scenario, namely those of municipal sorting and landfilling, were not included in the assessment. The reason for this stands in the fact that such trays are delivered to mass retailers located all over the Italian territory and so lots of those plants come to be part of their end-of-life phase. For this reason, high rates of variability were found by the authors to be associated with locations of the aforementioned plants. As a consequence, the transport system associated with SS4 was not modelled and the related transportation flows, expressed as kg*km, were not estimated.

In addition to the above, it is underscored that the end-of-life stage of the plastic bags used as packages for the trays to be delivered was not taken into account, too. The authors did so due to the difficulty of data collection and modelling, and also because, in the light of the almost negligible amounts implied for trays packaging, very low environmental impacts were expected compared to the other phases such as, for instance, tray production.

The system boundaries were depicted in Fig. 2 in which all the main activities and both materials and energy flows were indicated in qualitative terms. There is evidence that the scrap material produced during thermoforming is regenerated and re-input to the extrusion process.

Fig. 2. Boundaries of the system under investigation[3]

2.3 Life Cycle Inventory

This stage of study was developed in order to quantify the usage of resources and materials and the consumption of energy, as well as the involved transports associated with the life-cycle of the analysed FU. For this purpose, production process of the trays were studied with consideration to details in order to obtain required information about merits of processes and both materials and energy used (Fig. 1 and 2). For LCI to be carried out, since a particular specialised production system was assessed, using primary data attracted great importance. In particular, the latter were supplied by the firm involved and mainly concerned consumption of input resources, materials and energy. The processes used for representing the extraction of resources, the production of both materials and energy, as well as the life-cycle of the transport means involved, were extrapolated from the Ecoinvent database system, because the latter is acknowledged worldwide to be a reliable background data source. Indeed, it accommodates most of the background materials and processes often required in LCA case studies (Frischknecht and Rebitzer, 2005). Data collection was carried out continuously accessing the aforementioned database system in order to verify which kind of processes and raw materials were needed to be specifically created. From this point of view, it was observed that all the required supportive data were already inserted to Ecoinvent.

In particular, as regards the trays' end-of-life, due to the difficulty of collecting primary data for the reasons previously explained, this phase was implemented using the model of sanitary landfill for MSW already contained in Ecoinvent.

All the data required for implementation of the phases of tray production and delivering was listed in Table 2, thereby enabling greater understanding of the study conducted. All the materials and processes indicated in Table 2 were extrapolated from Ecoinvent, based upon primary data provided by the firm.

Table 2
Input data for implementation of tray production and delivering phases[4]

The values of transports shown in Table 2 were detailed in Fig. 3 in which transported amounts, travelled distances, diesel consumption as well as type of means used were indicated. In particular, as regards transport of 1 kg packed trays to users, it was done as was at study of Siracusa et al. (2014). As a matter of fact, the transportation flow amount reported in Table 2 (580 kg*km) was

[3] Source: personal elaboration

[4] Source: personal elaboration based upon data provided by the firm involved

calculated as weighted average, based upon distances between tray manufacturing plant and users. For this purpose, the authors took into account not only the travelled kilometres but also the supply frequency.

Fig. 3. Input material transports[5]

2.3.1 Input data and damage allocation

All data demanded for the study development were collected on site and then allocated to the system for required investigations, using appropriately defined procedures and tools. In particular, interviews were made with the firm technicians during visits at the production site and then all data and information gathered were recorded in appropriately designed check-lists, thus facilitating revision and subsequent elaboration. Moreover, in-depth meetings with the aforementioned technicians as well as with the managers of the production and the environmental quality divisions were made in order to assure common understanding of the questions posed and their consistency with the objective of the study.

Finally, as regards the environmental impacts associated with the tray's life-cycle, because no co-products were considered, no allocation was done in accordance with the ISO standards: 100% of the environmental impacts corresponded, indeed, to the system's FU.

3. Results and discussion

3.1. Life Cycle Impact Assessment

The LCIA highlighted that the total damage associated with the analysed system is equal to 0.00156 pt and is mainly due to production of 1 kg of PS granule: indeed, this phase contributes to that damage for 69.3%, corresponding to 0.00108 pt. In addition, consumption of the electricity required for the whole process (1.417 kWh) covers 14.5% of the total damage. The other materials and processes comprised by the system boundaries, including all transports involved and the end-of-life phase, represent the remaining 16.2% of the total damage. For greater understanding, Fig. 4 was reported in order to show single-score results per damage categories. Hence, the total damage mentioned above can be easily calculated by summing up, for instance, the total amounts corresponding to the inputs depicted in the figure. Moreover, in Fig.4 for each single input-item considered, each damage category was allocated a weighing point. Doing so enabled documenting that *Resources* is the one to be mostly affected by the system due to the high contribution coming

[5] Source: personal elaboration using data provided by the firm. Images of the mean and of the manufacturing plant were downloaded from dreamstime.com

from production of 1 kg PS-granule. Reduced impacts occur to *Climate Change* and *Human Health*, in a more evident manner for PS-granule production; whilst, the damage affecting *Ecosystem Quality* can be considered as almost negligible for all inputs taken into account.

Fig. 4. Single-score evaluation per damage category[6]

Finally, from Fig. 4 the damage values (per single damage category) associated with process inputs considered were summed up: the resulting totals were listed in Table 3 together with the damage assessment values.

Table 3
Weighing points and damage assessment (values per damage category)

The system output flows (resources used and substances emitted) most affecting the aforementioned damage categories were listed in Table 4 and were associated to the related inventory amounts and damages caused per kg of packed trays. The processes mostly contributing to both consumption of those resources and emission of those substances were also indicated.

Table 4
Substances emission and resources consumption (values per kg of packed trays)

For better understanding, it is underscored that all resources and substances listed in Table 4 could be considered as the most significant impact-indicators to be taken into account in order to find ways for improved environmental sustainability of tray-production system design, implementation and management. Finally, as regards the impact categories, from Fig. 5 there is evidence that those with the highest contributions to total damage are: *Non-Renewable Energy*; *Global Warming*; and, *Respiratory Inorganics*. These impact categories were reported in Table 5 in association with both damage points and characterisation values (mid- and end-point approach results).

Fig. 5. Weighing per impact category[7]

Table 5
Weighing points and the characterisation values for each of the impact categories causing the greatest damage

3.2. Interpretation and improvement

The study developed attained the objective defined and, indeed, enabled understanding that the most impacting phase is 1 kg PS-granule production followed by electricity consumption and

[6] Source: personal elaboration based upon LCIA-results from Impact 2002+

[7] Source: Source: personal elaboration based upon LCIA-results from Impact 2002+

transport of both input materials and 1 kg trays. Moreover, thanks to the study here discussed it was possible to observe that:

- the most affected damage category is *Resources* due to the consumption of crude oil and natural gas in the amounts equal to 1.247 kg and 1.252 m^3, respectively;
- the most significant impact categories are *Non-Renewable Energy*, *Global Warming* and, *Respiratory Inorganics*.

For what concerns to the emitted substances, the most impacting one is carbon dioxide with a damage value levelling out at 4.18E-4 pt due to the high contributions coming from granule production and electricity consumption. In addition, Nitrogen oxides (NO_x), as emitted (to air) in the amount of 8.25 g, affect both *Human Health* and *Ecosystem Quality* and, in particular, more the former than the latter. This was considered by the authors as to be attributed to the classification scheme characterising the Impact 2002+ setting and, more specifically, to the characterisation and weighing factors which this method is based upon. However, for both damage categories, as evident from Table 4, NO_x-emissions are mainly due to granule production. The latter is the most contributing process for all the resources and substances considered but for zinc and aluminium where the greatest contributions mainly come from all the transports involved and from butane-1,4-diol production.

In this context, a flow chart of the damages being originated from the materials and processes encompassed by the system is shown in Fig. 6, where "Pt" stands for "weighing points" or "damage points" or simply "points".

Fig. 6. 1 kg trays' life-cycle: damage flows[8]

For greater understanding, it should be observed that those reported Fig. 5 and 6 represent the exact names (in the Ecoinvent database) of the inventories (materials, energy and processes), already reported in Table 2 and used for the assessment.

In the light of the obtained results, suitable solutions for damage reduction were addressed at the most impacting activities that characterise the production of the examined packaging product. In this regard, it should be observed that from meetings with the firm technicians it was emerged that:

- nothing can be done as per reduction of the amount of PS-granule used or as per usage of recycled granules because in both cases tray's functionality would be compromised;

[8] Source: personal elaboration of results from LCIA development as performed by Impact 2002+

- regarding road-transports, all the means used are euro 5 lorries, thus contributing to reduced GHG-emissions, and the distances travelled are strictly dependent on locations of both input material suppliers and tray users. In this sense, any change-decision should be made considering the internal policy and so should be operated by the competency management bodies of the firm.

For this reason, it was opted for the installation of a wind power plant (WPP) in order to supply, at least, the internal electricity requirements: in agreement with the technicians interviewed, a 150 kW nominal power was considered as feasible for the case. Therefore, the author team environmentally tested the aforementioned solution, as agreed with the technicians, in order to evaluate if it is effectively an improvement. For this purpose, no primary data were used and the model already existing in Ecoinvent v.2.2 was accessed. In particular, the latter provides accounting for the life-cycle of both moving and fixed parts as composing the WPP considered. In particular, besides production and disposal of those parts the dataset includes: the energy required for the assembly phase; the transports of the input materials to the manufacturing industries and of the manufactured WPP-parts to the tray production firm; the connection activities to the grid; and, the gear oil change needed for the correct working of the plant. For greater understanding, it should be observed that the module accounts for the share of WPP's life-cycle corresponding to production of 1 kWh electricity considering for the plant a 40-year lifetime and a 125 MWh average annual production. Therefore, it was used to model the tray production process by associating it with the related energy requirement (1.417 kWh/kg_{tray}).

From such an improvement proposal application, the authors could be proven right because the comparative assessment performed documented a damage reduction of almost 14%, from 1.56E-4 to 1.35E-4 pt (Fig. 7). In particular, carbon dioxide is reduced from 4.146 to 3.39 kg, whilst crude oil and natural gas are reduced from 1.247 to 1.19 kg and from 1.252 to 1.09 m^3, respectively.

Fig. 7. Environmental assessment of 1 kg tray's life-cycle with application of the proposed electricity-sourcing by wind power: a comparison with the initial study[9]

In the light of the results gained, there is evidence about the environmental sustainability of such renewable energy sources. However, more studies are needed to enable greater understanding of the technical feasibility and of the economic convenience associated with the solution proposed. Those issues were not addressed in the present study because the authors considered them as of strict competency of the firm technicians and so outside of the aim and scope of the study itself.

[9] Source: histogram extrapolated from Impact 2002+ (mPt: points E-3)

4. Conclusions

The study here presented was designed to investigate the food packaging field from an environmental point of view: its objective was, in fact, to perform LCA of the life-cycle of 1 kg trays for fresh meat packaging and preservation. The excellent cooperation of the producer allowed the team of researchers to effectively gather high-quality data, thereby making it possible to develop reliable results, thus forming a solid foundation for decision making at the firm level.

Development of the study enable the authors to document that most of the environmental impact associated with the system analysed comes from production of expandable PS granulates and from consumption of electricity as both required for tray manufacturing. This has to be attributed mainly to the exploitation of primary energy resources, such as crude oil and natural gas, and also to the emission (in air) of carbon dioxide, thereby contributing to affecting both non-renewable energy resource stock and climate change.

In the light of the findings of the study, the environmental improvement issue was addressed in order to enable reduction of the environmental impact associated with the system investigated and so to contribute to enhanced rates of sustainability. In this regard, in the occasion of meetings with the firm technicians it emerged that no improvements are possible to be made in the granule production and, more specifically, in terms of both amount and type used. This is because reduction of the PS-granule amounts to be implied or use of recycled granules would cause reduction of the functionality of the tray and so of its marketability. Furthermore, during those meetings the technicians clarified that no margins for improvement are possible as per all transports involved. In particular, all the means used are euro 5, so being characterised by GHG-emission rates largely compatible with the recent limits imposed by the European Commission, and the distances travelled are strictly dependent upon the locations of both input material suppliers and tray users. In this sense, any change-decision should be based upon the internal policy and so should be operated by the competency management bodies of the firm. In the light of the above, there is evidence of the existence of limiting conditions that cannot be neglected and so must be taken into due account for a more correct and pertinent planning of improvement interventions. In this context, the use of a wind power plant for sourcing the electricity demand for tray manufacturing was tested in agreement with the technicians, thus revealing a 14% environmental impact decrease.

Doing so made it possible for the authors to show that the use of renewable energy is a good mean for contribution to reduction of the environmental impacts associated with any industrial system, as the one investigated. Therefore, such energy production plants can help to enable production of more eco-friendly food packaging systems contributing, in turn, to enhanced environmental sustainability in the food SC.

In this context, it should be observed that the conclusions of the study are specific to the examined case, the obtained results, as well as the tray production technologies and the input data. Nevertheless, the study was designed to be as detailed as necessary to provide a useful contribution to the LCA approach in the food production and packaging sector. Based upon this research, all the targeted stakeholders may, indeed, be informed about the input/output flows involved in the system analysed, the related environmental impacts and the evaluable improvement potentials. In this way, the research-study developed will contribute to enriching the international knowledge on the environmental performance of 1 kg trays' life-cycle by providing reliable information on data inventoried and results obtained. Moreover, the authors believe that the study will enable understanding of how significantly the food packaging industry contributes to global climate change and environmental pollution, especially considering the huge amounts of packages produced. Therefore, solutions must be found to reduce such a contribution allowing, in turn, for implementation and development of cleaner production systems. In this regard, thanks to its findings, the present study could be used by the firm as the starting point for the development of more innovative and efficient packaging technologies in order to evaluate the alternative use of recycled and biodegradable polymers.

Acknowledgements

The authors declare that the study development was made for pure scientific research reasons and, indeed, no funding was received for this purpose.

Moreover, they would like to thank the tray producer for the excellent collaboration with the research group not only by providing all the necessary data and technical information, but also by allowing the researchers to visit the production plant and to interview the competency staff.

References

1. Accorsi, R., Cascini, A., Cholette, S., Manzini, R., & Mora, C. (2014a). Economic and environmental assessment of reusable plastic containers: A food catering supply chain case study. *International Journal of Production Economics*, *152*, 88-101.
2. Accorsi, R., Manzini, R., & Ferrari, E. (2014b). A comparison of shipping containers from technical, economic and environmental perspectives. *Transportation Research Part D: Transport and Environment*, *26*, 52-59.
3. Ahvenainen, R., & Heiniö, R.-L. (2006). Factors affecting the suitability of aluminium-foil trays for microwave oven heating: Comparison with plastic trays. *Packaging Technology and Science*, *5* 255-264.

4. Bare, J.C., Hofstetter, P., Pennington, D.W., & Udo de Haes, H.A. (2000). Midpoints versus Endpoints: The Sacrifices and Benefits. *International Journal of Life Cycle Assessment*, *5*, 319-326.
5. Bauer, C., Buchgeister, J., Hischier, R., Poganietz, W.R., Schebek, L., & Warsen, J. (2008). Towards a framework for life-cycle thinking in the assessment of nanotechnology. *Journal of Cleaner Production*, *16*, 910-926.
6. Bertoluci, G., Leroy, Y., & Olsson, A. (2014). Exploring the environmental impacts of olive packaging solutions for the European food market. *Journal of Cleaner production*, *64*, 234-243.
7. Díaz, P., Garrido, M., & Bañón, S. (2010). The effects of packaging method (vacuum pouch vs. plastic tray) on spoilage in a cook-chill pork-based dish kept under refrigeration. *Meat Science*, *84,* 538–544.
8. Ecoinvent (2011). The Swiss Centre for Life-cycle Inventories. Ecoinvent v2.2.
9. Frischknecht, R., & Rebitzer, G. (2005). The ecoinvent database system: a comprehensive web-based LCA database. *Journal of Cleaner Production*, *13*, 1337-1343.
10. Guinée, B., Reinout, H., Huppes, G., Zamagni, A., Masoni, P., Buonamici, R., et al. (2010). Life-cycle assessment: past, present, and future. *Environmental Science and Technology*, *45*, 90-96.
11. ILCD-handbook, (2010). "Analysis of existing Environmental Impact Assessment methodologies for use in Life Cycle Assessment (LCA)", Ispra. Italy.
12. Ingrao, C., Lo Giudice, A., Tricase, C., Mbohwa, C., & Rana, R. (2014). The use of basalt aggregates in the production of concrete for the prefabrication Industry – Environmental impact assessment, interpretation and improvement, *Journal of Cleaner Production*, *75,* 195-204.
13. Ingrao, C., Matarazzo, A., Tricase, C., Clasadonte, MT., & Huisingh, D (2015). Life Cycle Assessment for highlighting environmental hotspots in Sicilian peach production systems. *Journal of Cleaner Production*, *92,* 109-120.
14. International Organization for Standardization (ISO) (2006). Environmental management - Life-cycle assessment - Principles and framework. ISO 14040.
15. International Organization for Standardization (ISO) (2006). Environmental management - Life-cycle assessment – Requirements and Guidelines. ISO 14044.
16. IPCC, 2001. Climate change 2001: The Scientific Basis. Intergovernmental Panel on Climate Change (IPCC), htm://www.~rida.no/ climate/ipcc tar/, 385-391.

17. Jeswani, H.K., Azapagic, A., Schepelmann, P., & Ritthoff, M. (2010). Options for broadening and deepening the LCA approaches. *Journal of Cleaner Production, 12,* 120-127.
18. Joillet, O., Manuele, M., Raphael, C., Sébastian, H., Jérome, P., Gerald, R., et al. (2003). IMPACT 2002+: a new life cycle impact assessment methodology. *International Journal of Life Cycle Assessment*, *8*, 324 - 330.
19. Kaisangsri, N., Kerdchoechuen, O., & Laohakunjit, N. (2012). Biodegradable foam tray from cassava starch blended with natural fiber and chitosan. *Industrial Crops and Products*, *37*, 542–546.
20. Leceta, I., Guerrero, P., Cabezudo, S., & de la Caba, K. (2013). Environmental assessment of chitosan-based films. *Journal of Cleaner Production, 41*, 312-318.
21. Lo Giudice, A., Mbohwa, C., Clasadonte, M.T., & Ingrao, C. (2014). Life Cycle Assessment Interpretation and Improvement of the Sicilian artichokes production. *International Journal of Environmental Research*, *8,* 305 – 316.
22. Madival, S., Auras, R., Singh, S.P., & Narayan, R. (2009). Assessment of the environmental profile of PLA, PET and PS clamshell containers using LCA methodology. *Journal of Cleaner Production,17*, 1183–1194.
23. Marsh, K.& Bugusu, B. (2007). Food packaging – Roles, materials, and environmental issues. *Journal of Food Science*, *72*, 39-55.
24. Meneses. M., Pasqualino, J., & Castells, F. (2012). Environmental assessment of the milk life-cycle: The effect of packaging selection and the variability of milk production data. *Journal of Environmental Management*, *107*, 76-83.
25. Roes, A.L., & Patel, M.K. (2011). Environmental Assessment of a Sugar Cane Bagasse Food Tray Produced by Roots Biopack - Results of a Shortcut-Life-cycle Assessment. *Journal of Biobased Materials and Bioenergy, 5*, 140-152.
26. SimaPro (2006). LCA software and Database Manual. Prè Consultants BV, Amersfoort, The Netherlands.
27. Siracusa, V., Ingrao, C., Lo Giudice, A., Mbohwa, C., & Dalla Rosa, M. (2014). Environmental assessment of a multilayer polymer bag for food packaging and preservation: An LCA approach. *Food Research International*. *62*, 151 – 161.
28. Suwanmanee, U., Varabuntoonvit, V., Chaiwutthinan, P., Tajan, M., Mungcharoen, T., & Leejarkpai, T. (2013). Life Cycle assessment of single use thermoform boxes made from polystyrene (PS), polylactic acid, (PLA), and PLA/starch: cradle to consumer gate. *International Journal of Life Cycle Assessment, 18,* 401-417.

29. Williams, H., & Wikström, F. (2011). Environmental impact of packaging and food losses in a life-cycle perspective: a comparative analysis of five food items. *Journal of Cleaner Production*, *19,* 43-48.
30. Zampori, L., & Dotelli, G. (2014). Design of a sustainable packaging in the food sector by applying LCA. *International Journal of Life Cycle Assessment*, *19*, 206-217.
31. Zhou, G.H., Xu, X.L., & Liu, Y. (2010). Preservation Technologies for fresh meat – A review. *Meat Science, 86*, 119-128.