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

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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.

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, Cascini, Cholette, Manzini & Mora, 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 Organization for Standardization (ISO) 2006a, b), 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 a 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 (Ingrao, Matarazzo, Tricase, Clasadonte & Huisingh, 2015; Jeswani, Azapagic, Schepelmann & Ritthoff, 2010). A huge number of sectors such as automotive, buildings

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and construction, electronics, textile, agriculture, food production and packaging and so many others has used this methodology over the years (Madival, Auras, Singh & Narayan, 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 (Marsh & Bugusu, 2007; Accorsi, Manzini & Ferrari, 2014b; Bertoluci, Leroy & Olsson, 2014). Packaging should provide the following objects: 1) food quality and freshness conservation; 2) correct identification of product; and 3) convenience during storage and distribution (Meneses, Pasqualino & Castells, 2012; Williams & 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, Guerrero, Cabezudo & de la Caba, 2013; Zampori & 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, Kerdchoechuen, and Laohakunjit (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., 2010). 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 (Joillet et al., 2003) for LCIA development. As stated by Siracusa, Ingrao, Lo Giudice, Mbohwa, and Dalla Rosa (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 Joillet 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.

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 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, Lo Giudice, Tricase, Mbohwa, and Rana (2014), it allows

Table 1
Damage and Impact categories (Impact 2002 +).
Source: extrapolated from Joillet et al. (2003).

Damage category	Impact category
Human health	Carcinogens
	Non-carcinogens
	Respiratory inorganics
	Respiratory organics
	Ionizing radiations
	Ozone layer depletion
Ecosystem quality	Aquatic eco-toxicity
	Terrestrial eco-toxicity
	Terrestrial acidification/nitrification
	Aquatic acidiphication
	Aquatic eutrophication
	Land occupation
Climate change	Global warming
Resources	Non-renewable energy
	Mineral extraction