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Polylactic acid trays for fresh-food packaging: A Carbon Footprint assessment

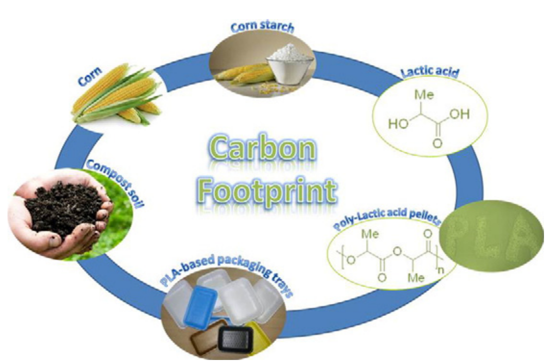
Carlo Ingrao [a,b,*], Caterina Tricase [a], Agnieszka Cholewa-Wójcik [c], Agnieszka Kawecka [c], Roberto Rana [a], Valentina Siracusa [b]

[a] *Department of Economics, University of Foggia, Via Romolo Caggese, 1-71121 Foggia, Italy*
[b] *Department of Industrial Engineering, University of Catania, Viale A. Doria 6-95125 Catania, Italy*
[c] *Department of Product Packaging, Cracow University of Economics, Rakowicka 27 St., Cracow, Poland*

HIGHLIGHTS

- The life-cycle of polylactic acid trays was modelled using Carbon Footprint (CF);
- The most impacting processes within the defined system boundary were highlighted;
- A comparison with conventional synthetic polymer trays were performed;
- Two different transport systems for polylactic acid granule supply were evaluated;
- The influence of transport on the CF associated with the system was so documented.

GRAPHICAL ABSTRACT



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ABSTRACT

This paper discusses application of Carbon Footprint (CF) for quantification of the 100-year Global Warming Potential (GWP_{100}) associated with the life cycle of polylactic acid (PLA) trays for packaging of fresh foods. A comparison with polystyrene (PS)-based trays was done considering two different transport system scenarios for PLA-granule supply to the tray production firm: a transoceanic freight vessel and an intercontinental freight aircraft. Doing so enabled estimation of the influence of the transportation phase on the GHG-emission rate associated with the PLA-trays' life cycle. From the assessment, the GWP_{100} resulted to be mainly due to PLA-granulate production and to its transportation to the tray manufacturing facility. Also, the study documented that, depending upon the transport system considered, the CF associated with the life cycle of the PLA trays can worsen so much that the latter are no longer GHG-emission saving as they are expected to be compared to the PS ones. Therefore, based upon the findings of the study, it was possible for the authors to understand the importance and the need of accounting for the transport-related issues in the design of PLA-based products, thus preserving their environmental soundness compared to traditional petroleum-based products.
In this context, the study could be used as the base to reconsider the merits of PLA usage for product manufacturing, especially when high distances are implied, as in this analysed case. So, the authors believe that new research

* Corresponding author at: Department of Economics, University of Foggia, Via Romolo Caggese, 1-71121 Foggia, Italy.
E-mail addresses: carlo.ingrao@unifg.it, ing.carloingrao@gmail.com (C. Ingrao).

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and policy frameworks should be designed and implemented for both development and promotion of more globally sustainable options.

1. Introduction

In the coming decades, it is expected that globalisation of commodities and their increasing consumption rates will lead to depletion of natural resources. In this regard, crude oil is acknowledged worldwide to be a major unsustainable resource: its consumption has caused an increase of the global atmospheric concentrations of carbon dioxide (CO_2) and methane (CH_4) to levels that have largely exceeded the natural ones (Sukan et al., 2015). The majority of plastics currently used are manufactured from crude oil and other fossil fuels, such as natural gas and coal. Moreover, their end-life prediction and, hence, their persistence in the environment go well beyond the predictable one (Blanco et al., 2011, 2013). The major usage of fossil fuels is to be attributed mainly to the chemistry of plastics that lends itself to the readily accessible constituents of petroleum and natural gas (Colwill et al., 2012; Hottle et al., 2013). In particular, Colwill et al. (2012) documented that production of plastics accounts for almost 4–5% of the global crude oil consumption. Along time, plastics have become more and more prevalent in daily life and, indeed, new technologies are increasingly being developed to improve their performance and functionality. However, just as gasoline and diesel will decrease in availability due to the increasing cost and scarcity of petroleum and other fossil fuels, so too will plastics made from fossil resources (Hottle et al., 2013). Nevertheless, agreeing with Colwill et al. (2012), resource depletion is not the only one problem to be faced, since CO_2 from fossil fuel combustion should be taken into consideration, too. It represents, indeed, a major contributor to global warming (GW) and could have potentially devastating social, economic and environmental consequences in the future, if not addressed (Colwill et al., 2012). This concern emphasises upon the need for alternatives to petroleum mineral-based products and processes. In fact, the continuous search for more environmentally sustainable solutions has been receiving the attention of a broad research community at the global level (Paiva et al., 2012). In this context, the concept of eco-friendly materials has been accepted by countries all over the world and, for this reason, new advanced materials are progressively being developed. For instance, biopolymers with their biodegradability, eco-friendly manufacturing processes and vast range of types and applications, presenting similar quality level as traditional materials, are quite valid to replace unsustainable products (Sukan et al., 2015). As a matter of fact, the development of biopolymers has been driven largely in response to the growing concerns regarding the sustainability of conventional polymers and the environmental pollution caused by plastic packaging waste (Colwill et al., 2012).

Biopolymers can be derived from renewable resources, as per polylactic acid (PLA), or partially made from renewable and synthesised ones, like traditional plastics: this is the case of bio-based polyethylene terephthalate (PET) (Hottle et al., 2013).

Biopolymers offer a renewable substitute to traditional petroleum-based plastics and can be obtained from different types of feedstock including agricultural products, such as corn or soybeans, and from other sources like algae or food waste (Flieger et al., 2003; Du and Yu, 2002; Landis et al., 2007; Hottle et al., 2013). Moreover, biodegradable polymers may be considered as a solution to waste-disposal problems associated with synthetic plastics. In particular, they represent a loosely defined family of polymers that are designed to degrade through series of actions from living organisms and offer a possible alternative to traditional non-biodegradable polymers where recycling is unpractical or not economically convenient (Mohanty et al., 2000). This is the case, for instance, of expanded polystyrene (EPS) trays for fresh-meat packaging: Ingrao et al. (2015a) stated, indeed, that such trays absorb blood released from the fresh meat contained and so come to be contaminated with varieties of microorganisms that make them suitable not for being recycled but for being disposed of in sanitary landfills as municipal solid wastes (MSWs). In contrast, the same trays could be disposed of in a compost plant if they were made of expanded PLA (EPLA) (or other suitable biopolymers). In this way, that contamination due to the prolonged contact with the meat-content would no longer represent a problem. Biodegradability is, in fact, one of the main reasons for the interest in biopolymers, because it answers to the need and urgency of environmentally sounding disposal scenarios. In this context, environmental studies are increasingly being developed in order to identify the best options to be practiced per analysed biomaterial. For instance, Hermann et al. (2011) and Guo et al. (2013) performed assessments of global environmental impact as well as carbon and energy footprints in order to compare different end-of-life scenarios for series of biomaterials. Moreover, the use of bioplastics would enable reduced exploitation of non-renewable primary-energy resources as well as reduced emissions of Greenhouse Gases (GHGs) (Mohanty et al., 2000).

All that stated, it could be concluded that biopolymers are valid alternative materials to those produced from fossil resources and it is quite so in nearly every function, from packaging and single use to durable products. In this regard, since such biodegradable plastics are capturing increasingly-larger shares of the global market, environmental studies are desirable to enable consumers and producers to identify more sustainable methods of use, production, and disposal for such products (Hottle et al., 2013).

In this context, the study here discussed regards application of Carbon Footprint (CF) for quantification of the 100-year Global Warming Potential (GWP_{100}) associated with the life cycle of EPLA trays for packaging of fresh food. The study is part of a research that was designed to environmentally investigate the life cycle of fresh-food packaging trays with the final aim of understanding if, in this field, biodegradable polymers are valid alternatives to the synthetic ones. The research included the study of Ingrao et al. (2015a) concerning application of Life Cycle Assessment (LCA) to EPS trays of equal dimensions and production technology compared to those made of EPLA that are the object of the present study. Here, the two types of tray (PS vs. PLA) were compared based upon the related GWP_{100} values, so highlighting those causing the lowest GHG-emissions. Another study will be carried out and focussed upon application of LCA with the aim of comparing the aforementioned tray-types in terms of global impact, thus including other environmental aspects such as, for instance, non-renewable energy and land use. According to the authors, doing so will enable integrated and detailed evaluations of the environmental performances related to the trays analysed and, as a result, enhanced knowledge in the field: for this purpose, all the assessments to be further needed will be developed by the authors. The authors believe that in this way the study could support in finding the most environmentally preferable packaging option, thus contributing also to global enhancement of the environmental sustainability associated with food supply chains (SCs).

Finally, for the readers to better enter into the merits of the field investigated and so to better understand the study conducted, in Section 2 material properties, commodity science aspects and, main types and uses related to PLA for usage in the packaging field were addressed.

2. Polylactic acid for food packaging

2.1. Material properties

PLA is a suitable alternative to petroleum-derived polymer materials. The lactide from which it is produced can be obtained by chemical