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Research article

Environmental impact of a new industrial process for the recovery and valorisation of packaging materials derived from packaged food waste

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ABSTRACT

In Italy, most of the packaged food wasted during the distribution phase and at retail stores is disposed of in landfill, due to the absence of a sorting system able to separate food from packaging.

A new experimental process, here presented, collects the packaged food waste from retailers, moves it to distribution centres, and then ships it to a sorting facility where the food is separated from its packaging. The sorted packaging materials are then sent to specific recycling or energy recovery centres, meaning that only a small amount of packaging material is disposed of in landfill.

In this study, the environmental performance of this innovative process is compared with the impacts generated by disposal in landfill using the Life Cycle Assessment (LCA) methodology. Data for the year 2015 in the Emilia Romagna region (Italy) was collated for this purpose; in this region, about 14,600 tons of food are wasted in the retail channel annually. The LCA is performed using the ReCiPe midpoint method; primary data was taken from the field, while secondary data came from literature and ecoinvent 3.3 databases. Three sensitivity analysis were carried out to evaluate the results when the distances covered during the transport phase, the composition of the packaging waste, or the EOL of the country where the analysis is performed varied.

Overall, the results show that the innovative scenario is more environmentally sound than the one currently in use. Taking into account the avoided impacts, the environmental impact turned out to be negative in all the categories, suggesting a beneficial effect on the environment.

1. Introduction

Food waste (FW) generated across the Food Value Chain (FVC) turns out to be one of the major problems relating to food production. In 2011, the United Nations Food and Agriculture Organization (FAO) estimated that more than one third of food produced (about 1.3 billion tons) is lost (Gustavsson et al., 2011; FAO, 2013a, b). Food can be wasted throughout the FVC, from primary production to the use phase (WRAP, 2007a, b; Fredriksen et al., 2010; European Commission, 2015).

Packaging is a main part of any food, as it is fundamental to ensure that its organoleptic and hygienic properties are preserved; also, it ensures protection and conservation of the food quality and can contribute to reducing FW (Bertoluci et al., 2014). The global volume of packaging materials manufactured and disposed every day has led many researchers to deal with the issue of environmental impact, especially in the food sector (Vermeulen et al., 2012). Several studies have been carried out since 1990 with the aim of demonstrating the impact of packaging materials in the food sector and the best end-of-life (EOL) valorisation option for different types of them. Lately, Manfredi and Vignali (2014) found that glass packaging is the main cause of environmental impact generated by the production of tomato puree, while Bertolini et al. (2016) and Manfredi and Vignali (2015) analysed the impacts of several packaging materials respectively used for milk and beverages. In recent years, several studies have demonstrated extending food's shelf life by means of an improved packaging solution could reduce the environmental impact of the whole packaged food, acting mainly on the reduction of the FW associated to it (Williams and Wikström, 2011; Grönman et al., 2013; Wikström et al., 2014; Manfredi et al., 2015).

The environmental impact of FW treatment has been studied extensively using the Life Cycle Assessment (LCA) method. In this study, however, we focus on the specific issue of valorising the packaging fraction of packaged food waste (PFW), i.e. the packaged food discarded at retail stores. "Valorisation" means any option where the packaging material is not disposed of in landfill, according to European Commission (2008) guidelines. The main problem associated to PFW consists in the impossibility to recover

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its packaging material, by separating it from the wasted food. In turn, this is primarily due to the lack of system able to mechanically separate the FW from its packaging. Consequently, at present all the PFW collected during the retail and distribution phases is then sent to landfilling or incinerated (Garcia-Garcia et al., 2015).

Based on these premises, this study aims to explore different valorisation options for primary packaging deriving from packaged food wasted at retail stores. In particular, it will show how an innovative process, consisting of an appropriate collection and sorting system for PFW, could be an effective valorisation option from an environmental point of view. The objective of this study, which is supported by the LCA methodology, is to evaluate the environmental performance of this new process for the sorted packaging materials compared to the current one (i.e. disposal in landfill). As it targets packaging materials, the analysis excludes the environmental impact of the FW disposed of in landfill.

This work is a part of the SORT project,[1] Italian acronym for "Technologies and models to unpack, manage inventory and track wasted food". The aim of the project is to valorise the packaged food waste collected from retail stores, in order to recover the product and its packaging.

The paper is organised as follows. After a literature review on EOL valorisation of PFW and packaging materials (Section 2), the LCA methodology is applied taking into account the phases described in ISO 14044 (Section 3). Environmental impact assessment is then performed considering the current scenario and comparing it with the new one. A sensitivity analysis is then carried out to show how different contexts could affect results (Section 4). Finally, the conclusion section summarises the main findings from this work and underlines activities for future research.

2. Literature review on packaged food waste and packaging material EOL valorisation

A literature review on EOL valorisation of PFW and packaging materials has been done in order to underline the research activities in the fields of PFW valorisation and possible EOL of the packaging materials associated to food waste. Both the systematic have been carried out using the Scopus database, provided by Elsevier.

2.1. Packaged food waste

The collected articles concerning the PFW cover a timespan from 2008 to 2018. They have been obtained by carrying out a query with the following set of keywords: "food waste", "valorisation" and "packaging". This query returned 112 articles, but only five of them are strictly related to the EOL management of PFW, which is the focus of this study. In particular, the articles excluded from the analysis analysed either unpacked FW or general issues of FW management, or carried out surveys on FW in household.

Looking at the pertinent studies, the main EOL valorisation options of PFW are:

- Animal feed, anaerobic digestion and composting (Garcia-Garcia et al., 2015, 2017; Salemdeeb et al., 2017);
- Animal feed, anaerobic digestion, incineration (Vandermeersch et al., 2014);
- Animal feed, anaerobic digestion, incineration, landfill, compost and donation (Eriksson et al., 2015).

As reported in Garcia-Garcia et al. (2017, Fig. 3), the less preferred options of EOL valorisation of PFW are landfilling and thermal treatment with energy recovery. As far as the incineration and landfill are concerned, the unpacking phase is not strictly necessary (Garcia-Garcia et al., 2017). Conversely, to reduce the environmental impacts of the wasted food separated from the packaging, different waste management alternatives are suggested, such as composting and anaerobic digestion, for which the food needs to be unpacked before its treatment. Moreover, according to the European guidelines, the FW should preferentially be used as animal feed (Salemdeeb et al., 2017). To this end, the PFW has to be unpacked, with technologies that provide a minimum damage to the food and do not adulterate its matrix. In addition, each type of PFW must be treated individually, to avoid possible cross-contaminations (Garcia-Garcia et al., 2017).

Although the studies reviewed above focuses on PFW, none of them have analyses the techniques to recover packaging from PFW after a sorting phase. Consequently, the description of the unpacking and sorting processes are not dealt with in these papers. PFW consisting of expired or wasted products from retailers and. The present paper tries to bridge this gap of knowledge by proposing an innovative system of sorting, unpacking, inventory management and track of PFW and evaluating its environmental impact.

2.2. EOL valorisation of packaging

As the LCA analysis focuses on the valorisation of packaging materials separated from FW, this section reviews the studies relating to the EOL valorisation options of different packaging materials. Table 1 summarises some of the main works concerning the valorisation of packaging materials, again on a timespan from 2008 to 2018; later on we will refer to the most recent and detailed works, related to the valorisation of the different types of packaging materials. The articles have been retrieved by carrying out a query with the following set of keywords: "packaging", and "end-of-life". This query returned 169 articles, and 31 of them are strictly related to the EOL management of packaging materials.

According to Licciardello (2017), food packaging sustainability can be achieved at three levels: (1) at raw material level, by using recycled materials and renewable resources; (2) at production level, using more energy efficient processes; (3) at waste management level, by reusing, recycling and biodegradation. This paper then focuses on points 1 and 3, analysing the following materials:

Plastic: Recycling is the preferred solution for plastic waste management (*Polyethylene (PE)*, *Polyethylene terephthalate (PET)*, *Polypropylene (PP)*, etc.), because it has a lower environmental impact in several impact categories ranging from global warming to human toxicity indicators (Al-Maaded et al., 2012). The main benefits arise from the avoided production of virgin plastic, as confirmed by most recent articles in this field (Gu et al., 2017; Malik et al., 2017).

Paper: According to the literature reviewed, the worst option for paper and cardboard waste management is landfilling, in particular when considering the impact on climate change potential and energy demand. The comparison between recycling and incineration is more complex. If we only consider energy demand and water consumption, recycling is preferable to incineration, but they are comparable if we consider climate change. Compared to landfill, the main advantage of incineration is the substitution of fossil fuels, whereas incinerators provide heat and electricity. For recycling, the advantage is the wood resources saved, which can be used for producing paper or generating energy, i.e. from renewable fuel, which does not contribute to global warming (Merrild et al., 2008).

Glass: the literature regarding the treatment of glass waste is limited. A possible reason is that the energy required to process

[1] Tecnologie e modelli per lo Spacchettamento, l'ORganizzazione delle scorte e il Tracciamento dei prodotti alimentari sprecati.