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Life cycle assessment of end-of-life options for two biodegradable packaging materials: sound application of the European waste hierarchy

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ABSTRACT

The purpose of this study is to assess whether for dry biodegradable packaging without food contamination, a detailed life cycle assessment supports the priorities suggested by the five-level hierarchy, as described by the European Waste Directive 2006/12/EC. Environmental impacts and water withdrawal were assessed using an extended version of IMPACT 2002+, accounting for the dynamic pattern of greenhouse gas releases for each scenario when determining Global Warming Potentials for a time horizon of 100 years (in this paper defined as dynamic assessment).

The present assessment shows that, for most impact categories, mechanical recycling is the most interesting option, followed by direct fuel substitution. Intermediate performances are obtained by anaerobic digestion and municipal incineration. Landfill and industrial composting of dry packaging generate the highest environmental impacts of the studied end-of-life options. Indeed, the composting of the studied materials does not substantially improve compost quality and does not enable energy recovery.

The hypothesis that composting is by default environmentally preferable over energy recovery because it is a form of recycling is not confirmed by the present study, thus underlining the importance of a sound and case-specific application of the EU waste hierarchy and the need to complete the hierarchy by product specific studies.

Though of limited effect on the present study, the dynamic assessment of greenhouse gas may moderately decrease the impacts effectively taking place over the 100-year horizon. More important is to consider the degradation patterns of biodegradable materials and present to the decision makers both the 100-year and the long term impacts of the end-of-life options.

1. Introduction

The waste hierarchy concept as initially introduced by the European Commission in the European Waste Directive 2006/12/EC (The European Parliament and Council, 2006) included the following three parts: 1. Prevention and Reuse, 2. Recycling and Recovery, and 3. Disposal. The three-level hierarchy has been replaced by a five-level hierarchy including: 1. Prevention, 2. Reuse, 3. Recycling, 4. Other recovery, and 5. Disposal, maintained in broad lines in the revised waste framework Directive 2008/98/EC (The European Parliament and Council, 2008). Recital 31 of this revised Directive[1] clearly supports the understanding that deviations from the hierarchy are acceptable in cases where other priorities would be more environmentally favourable (Manfredi et al., 2011), applying life cycle thinking as suggested by Lazarevic et al. (2012). Flexibility in applying the revised framework is in particular required because of variations in environmental conditions.

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[1] 2008/98/EC, Recital 31: “The waste hierarchy generally lays down a priority order of what constitutes the best overall environmental option in waste legislation and policy, while departing from such hierarchy may be necessary for specific waste streams when justified for reasons of, inter alia, technical feasibility, economic viability and environmental protection.”

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For new applications, it is therefore important to analyse in further detail which scenarios are preferable. Biodegradable plastics constitute an interesting case since they can be treated in all end-of-life options outlined in the hierarchy, including composting and anaerobic digestion. On the one hand, public perception towards composting and biodegradation has been particularly positive (Bidlingmaier et al., 2003). Biodegradation has frequently been claimed to be a sustainable solution for polymers (Narayan, 1994), mentioned as "the most relevant waste treatment technology for biodegradable plastics" (Ren, 2003) or used as a claim for environmental benefits in itself, without substantiation, as shown by Muse (2010). This founded or reinforced the idea that a biodegradable plastic is an "organic material" in the sense of the Directive 2008/98/EC, hence its composting could be called recycling,[2] leading to a narrow interpretation of the directive that composting is necessarily environmentally preferable over energy recovery. In addition, public and authority acceptance of energy recovery through incineration is limited in certain regions, and has resulted in local hierarchies of preferences within the "other recovery" category.

On the other hand, Finnveden et al. (2007) conclude that "composting has few advantages over biodigestion and incineration". Several authors have studied the environmental consequences of a limited number of end-of-life treatments (e.g. Björklund and Finnveden, 2005; Finnveden et al., 2005; Detzel and Krüger, 2006; Eriksson et al., 2005; Hermann et al., 2011) showing that recycling is in general the best end-of-life option and composting the least interesting. A DEFRA (2011) report systematically places landfilling as the least preferable option and suggests that composting is not the preferred option for food, garden waste and lower grade wood, but does not mention biodegradable polymers in this list. Razza and Innocenti (2012) showed that biodegradable wet food packaging can contribute to an increase in the composting rate of food waste and the quality of composts. However the environmental performances of several disposal options need to be explored for the specific case of used dry packaging made of biodegradable plastics.

In addition, the release pattern and time of greenhouse gas emissions (GHG) has traditionally been neglected in LCA (Brandão et al., 2013). However, the dynamic of the CO_2 and CH_4 releases vary widely between biodegradable materials and end-of-life options. For example most of thermoplastic starch (TPS) is biodegraded within a 100 year time horizon in landfill, whereas only a very limited fraction of polylactic acid (PLA) is degraded. While ECJRC-IES (2010) suggests accounting for delayed releases using a fixed reduction of 0.01 $year^{-1}$, such a linear assumption does not accurately account for the pattern of greenhouse effect over time. Levasseur et al. (2013) show that such temporary storage does matter for biomass. Thus, there is a need to model and take into account the dynamic of greenhouse gas releases specific to each end-of-life treatment of biomaterials.

The objective of this study is to compare in detail the life cycle environmental impacts of six end-of-life options of two biodegradable materials, polylactic acid (PLA) and thermoplastic starch (TPS), used for *dry* packaging,[3] while accounting for the dynamic pattern of greenhouse gas releases for each combination of material and end-of-life treatment. The purpose is to assess whether for biodegradable dry packaging, a detailed life cycle assessment supports or not the priorities suggested by the five-level hierarchy. The focus of the study is on the end-of-life treatments of dry packaging (as opposed to wet packaging, contaminated with food residues). The focus is not on the packaging materials themselves which can only be studied in the context of a given application.

2. Methodology

2.1. Selected materials and end-of-life options

PLA and TPS were the selected packaging materials. The shape and characteristics of the dry packaging affect the compostability of these materials, hence it is considered that the resulting packaging meet the biodegradability criteria set in prevailing EU standards such as EN 13432 (CEN, 2000). Among the possible treatment alternatives, we selected six end-of-life options that cover the different levels of the EU waste treatment hierarchy. The following alternatives are either currently available for food packaging or may realistically become available on a large scale in the near future, provided that government policies favour such end-of-life options if they are shown to be environmentally preferable: mechanical recycling (MR), industrial composting (IC), anaerobic digestion (AD) (also called methanisation), direct fuel substitution in industrial facilities (DFS), incineration with heat recovery in municipal solid waste incinerators (MSWI) and landfilling (LF).

The **functional unit** is the end-of-life treatment of 1 kg of dry packaging material, as disposed of by a consumer.

2.2. System description

Fig. 1 shows the product system considered: it covers the full packaging life cycle, including primary material production and delivery, transformation into polymer resin as well as end-of-life treatment. The material production is included because the recycling credit considers avoiding primary material. The final product manufacturing, the distribution and the use stages are not considered within the scope of this paper. Hence, forming, labelling and printing are excluded from the study; however, recycling process includes purification of the recovered material. Material and energy recoveries are modelled using a system expansion, substituting background material and energy carriers, as described in the Life cycle inventory section. Europe has been chosen as the region of disposal. These are "average" scenarios which could be

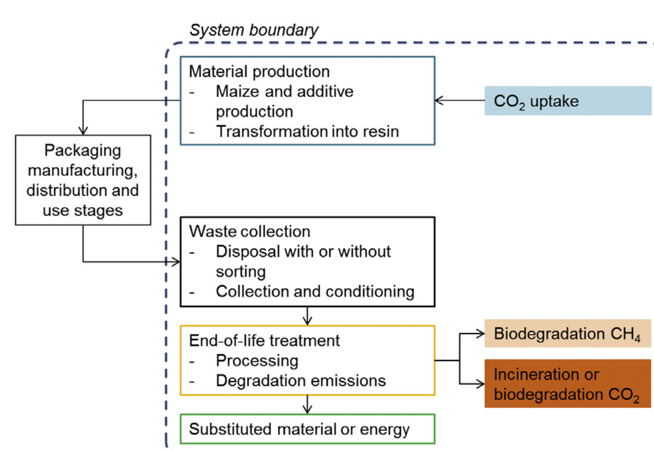

Fig. 1. PLA and TPS life cycle and boundary of the studied system. CO_2 uptake and CO_2 and CH_4 emissions occurring during the end-of-life treatment are highlighted in this system boundary diagram and in the results graphs.

[2] Directive 2008/98/EC, Art 3, al 17: "recycling" means any recovery operation by which waste materials are reprocessed into products, materials or substances whether for the original or other purposes. It includes the reprocessing of organic material but does not include energy recovery and the reprocessing into materials that are to be used as fuels or for backfilling operations.

[3] For instance: packaging for non-food products; packaging for dry food such as crockets, cookies, pasta, chewing-gums; secondary packaging of any product.