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Environmental evaluation of plastic waste management scenarios

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ABSTRACT

The management of the plastic fraction is one of the most debated issues in the discussion on integrated municipal solid waste systems. Both material and energy recovery can be performed on such a waste stream, and different separate collection schemes can be implemented. The aim of the paper is to contribute to the debate, based on the analysis of different plastic waste recovery routes. Five scenarios were defined and modelled with a life cycle assessment approach using the EASEWASTE model. In the baseline scenario (P0) the plastic is treated as residual waste and routed partly to incineration with energy recovery and partly to mechanical biological treatment. A range of potential improvements in plastic management is introduced in the other four scenarios (P1–P4). P1 includes a source separation of clean plastic fractions for material recycling, whereas P2 a source separation of mixed plastic fraction for mechanical upgrading and separation into specific polymer types, with the residual plastic fraction being down-cycled and used for “wood items”. In P3 a mixed plastic fraction is source separated together with metals in a “dry bin”. In P4 plastic is mechanically separated from residual waste prior to incineration.

A sensitivity analysis on the marginal energy was carried out. Scenarios were modelled as a first step assuming that marginal electricity and heat were based on coal and on a mix of fuels and then, in the sensitivity analysis, the marginal energy was based on natural gas.

The study confirmed the difficulty to clearly identify an optimal strategy for plastic waste management. In fact none of the examined scenarios emerged univocally as the best option for all impact categories. When moving from the P0 treatment strategy to the other scenarios, substantial improvements can be obtained for “Global Warming”. For the other impact categories, results are affected by the assumption about the substituted marginal energy. Nevertheless, irrespective of the assumptions on marginal energy, scenario P4, which implies the highest quantities of specific polymer types sent to recycling, resulted the best option in most impact categories.

1. Introduction

Plastic constitutes an increasingly important fraction of municipal solid waste (MSW) and in Europe it is much debated how this waste fraction should be managed. The paper by Lazarevic et al. (2010) is a useful guidance about the most convenient management schemes for this material. Based on an extensive literature review, seventy seven scenarios were selected and classified into four categories, based on the dominant technology in the scenario: mechanical recycling, feedstock recycling, incineration, landfilling. The conclusion of the study is that mechanical recycling is generally the best option, even if changes in the virgin material substitution ratio and in the level of organic contamination can make incineration preferable. Shonfield (2008) reported the life cycle assessment (LCA) of a range of plastic recovery technologies, including comparisons between different options for the disposal of plastic contained in household waste. The results are particularly sensitive to the quality of the produced plastic, which influences the virgin material substitution ratio: the best choice is to focus on technologies that produce high quality recyclate; when it is not possible to obtain an adequate quality, plastic should be used in the production of refuse derived fuel (RDF) or as a reducing agent in blast furnaces. Astrup et al. (2009) in their study concluded that the substitution of virgin plastic is the preferred option when the source separated plastic is of good quality; when dealing with mixed plastics, its use as a fuel in substitution of coal is the environmentally preferable option. The substitution of wood should be avoided when considering the effects on global warming. Also Al-Salem et al. (2009) reviewed the recovery routes for plastic waste, coming to the conclusion that both material recycling and energy recovery in different forms play a role in the sustainability of the end of life of municipal waste derived plastic items.

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There is a general agreement on the fact that clean fractions of individual plastic polymers should be recycled, but the debate is still open on how to properly manage the mixed and potentially dirty plastics found in waste. It has to be assessed whether the benefits of recycling or recovery of such streams outweigh the efforts for their separate collection. For example, Frees (2002) found that extensive cleaning of food containers using hot water may lead to energy consumption comparable to the energy gained from incineration of the containers.

2. Materials and methods

2.1. Goal and scope

The aim of the paper is to contribute to the existing debate around plastic waste management. As both material and energy recovery can be performed on such a waste stream, and different separate collection schemes can be implemented, different plastic waste recovery routes were analysed. Goal of the study was thus to compare, following a life cycle approach, different options for the management of plastic fraction, in order to address the challenges associated with such a critical material.

Five scenarios were modelled. In the baseline scenario (P0) the plastic is not source separated at all, which means that it is treated together with the residual waste (RW); 90% is sent to a waste-to-energy plant (WTE), while 10% to a mechanical-biological treatment plant (MBT) producing RDF. In scenarios P1–P4, a range of potential improvements in plastic management is introduced, meaning that out of the total plastic present in the gross waste, a certain amount is separated at the source (P1–P3) or by introducing a dedicated material recovery facility (MRF), for P4. Section 2.3 describes in detail the scenarios.

The functional unit is the management of 1 tonne of plastic as present in the gross waste. A typical waste composition of Western Europe was selected, as reported in Møller et al. (2012) (Table SM.1 of Supplementary Material). MSW produced in this region has a relatively high content of paper and a medium content of kitchen waste, while total plastic represents 10% in weight. Section 2.2 reports the composition of the plastic fraction.

System boundaries include the treatment in the MRFs, the plastic recycling, and the WTE and MBT plants. Waste collection and transport were included, too. Section 2.5 reports the inventory data used in the modelling.

Beyond treating waste, some of the analysed activities (e.g. plastic recycling and energy recovery from the RW) allow for the production of secondary materials and/or energy. These are called "multifunctional" processes, and the supplementary functional outputs are called "co-products". In the LCA modelling, instead of using allocation between functions, we have identified which products are replaced on the markets by the arising co-products and we have included their replacement in the model. This methodology is called "substitution by system expansion" or "avoided burden method" (Finnveden et al., 2009). The system was modelled using a consequential LCA approach, i.e. by identifying and modelling marginal technologies for energy production and other technologies affected by changes in the waste management system. The possibility of cascade effects from increased capacity of the waste-to-energy (WTE) plants involving diversion of other waste types to incineration were not considered. The long-term marginal for electricity was assumed to be produced at coal-based power plants. This was also identified as the most widely used electricity marginal by Mathiesen et al. (2007) who reviewed a number of articles on LCA of energy systems. As it is difficult to identify the marginal heat because district heating comprise of many small independent networks, an average heat mix was constructed based on data on European fuel mixes for heat production (IEA, 2010).

Table 1
Composition of plastic in municipal solid waste.

Distribution of plastic fraction (% wet weight)	Average
Bottles	27
Soft	36
Hard	11
Non-recyclable	26

The analysis was carried out with the LCA-waste-model EASEWASTE (Environmental Assessment of Solid Waste Systems and Technologies) developed by DTU Environment, Technical University of Denmark, and described in details by Kirkeby et al. (2006). Section 2.4 illustrates the adopted characterisation method and the selected impact categories.

2.2. The plastic fraction

The plastic in MSW is composed of plastic bottles made of polyethylene terephthalate (PET) or high density polyethylene (HDPE), of soft plastic or plastic films made of low density polyethylene (LDPE) and of hard plastic made of HDPE. The remaining plastic material fraction is regarded as non-recyclable mixed plastic.

The distribution of the four fractions out of the total plastic in MSW is shown in Table 1, and it was calculated as an average of data from Italy (Corepla, 2011) and France (ADEME, 2009). The assumed polymer composition of plastic material fraction is based on data from Italy and shown in Table 2.

2.3. Plastic waste management scenarios

As a general approach, plastic waste management scenarios were defined by taking into account the peculiarity of this material and some of the most common practices in Europe. When compared to other packaging materials (iron, aluminium, paper, etc.) what is commonly referred to as "plastic" is in fact still a very heterogeneous fraction. As a consequence, an important sorting step is required prior to recycling, aimed at:

- removing non-plastics fractions,
- sorting by different polymers (PET, PE),
- sorting by different colours (PET only).

After sorting, the different plastic flows are sent to the recycling process, which yields some further residues.

The modelled scenarios are:

- P0: Plastic is not collected separately, nor it is mechanically sorted from the RW. The plastic is thus treated as RW according to the following hypothesis: 90% in weight to WTE and 10% in weight to MBT.

Table 2
Polymer composition of plastic fractions in municipal solid waste in Italy (Corepla, 2011).

Material plastic fraction (% wet weight)	PET	PE		Mix
		LDPE	HDPE	
Bottles	25		8	
Soft		39		
Hard			5	
Non-recyclable				23
Total (%)	25	39	13	23