

ASSESSING THE ROLE OF THE TYPE OF COLLECTION BAG IN THE MANAGEMENT OF FOOD WASTE

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More than 7 million tonnes of organic fraction were separately collected in Italy in 2018, following a robust increasing trend. Its treatment is progressively shifting towards anaerobic digestion instead of composting, with about 3 million tonnes currently being processed in integrated anaerobic/aerobic treatment plants or in purely anaerobic ones. The bag used for the organic waste collection is crucial in determining the overall performance of the system, since there is a mounting evidence that bioplastic bags, especially in the form of shoppers, might cause problems during the anaerobic treatment. On the other hand, paper bags allow for a smoother operation of the plant, since they don't need to be removed upstream. This project aims to analyse the environmental performances of the full treatment chain of the organic waste processed with anaerobic digestion, starting from the assessment of the weight losses during the household storage, and the considering the different behaviour of the bags at the treatment plant. In particular, the degradation potential and the corresponding biomethane production of the different typologies of bag were evaluated at the laboratory level, by means of BMP (Biochemical Methane Potential) tests carried out under different conditions (temperature, inoculum). To assess the performances of the overall organic waste treatment chain, a comparative Life Cycle Assessment for the two types of collection bag has been carried out, including all stages: the production and supply of raw materials, the production of the bags and their distribution, the bag use, the collection and treatment of the organic waste.

Keywords: paper, bioplastic, food waste, anaerobic digestion, life cycle assessment

Introduction

The organic fraction, mostly composed by food waste, is the most relevant municipal waste stream separately collected in Italy, with 6.4 million tonnes per year, continuously growing (ISPRA, 2020).

Because of the biodegradable properties of food waste, the typology of collection bag has an important influence on its management, both at the domestic level and during the treatment at the recovery plants.

Bioplastic bags determine a series of potential problems, in particular when sent to wet and semi-dry anaerobic digestion plants: their removal is typically required before the digestion process. Moreover, their shape causes the dragging and the subsequent removal from the treatment of a non-negligible amount of food waste. This leads to a lower production of biogas and to an important increase of the process residues. On the contrary, paper bags are more compatible with the anaerobic digestion process and therefore their removal is not required.

The goal of the present project was the investigation of the environmental and energy performance of the overall food waste management chain (household storage, collection, transport, treatment, and management of residues streams), with a particular reference to the different typologies of collection bag.

Materials and Methods

In this project, the following aspects were evaluated to assess how the food waste source separation is affected by the typology of bag used for the collection:

- the weight losses during the food waste household storage;
- the amount of methane achievable from bags with the anaerobic digestion process by means of lab-scale Biochemical Methane Potential (BMP) tests.

Finally, a Life Cycle Assessment (LCA) of the overall food waste management chain was performed.

In all the evaluations, the following different types of food waste collection bags were compared:

- bioplastic bags made of Mater-Bi®. These bags exist in two types: those that are specifically designed and sold for the food waste collection (dedicated) and the conventional shopping bags that, after being used for the purchase at the supermarket, can be re-used for the collection of the food waste fraction (shopper);
- bags made of recycled paper with a reinforced bottom, specifically manufactured for the food waste collection.

The first comparison between bioplastic and paper bags was performed at the level of waste generation. In detail, the waste weight loss during the time occurring between the delivery in the bag by the user and the collection was analysed performing 112 tests in parallel for paper and bioplastic bags placed inside aerated bins (Dolci et al., 2021). For each test, the following stages were performed: homogenisation of the generated food waste before each bag filling; subdivision of the food waste into two portions with the same weight; discharge of the two portions respectively in the paper and in the bioplastic bag. The duration of each test was about 120 hours (5 days). At the end of the test, the two bags were removed after the evaluation of the weight losses with respect to the inserted waste. This aspect is relevant because weight losses have consequences on the amount (and potentially on the quality) of the waste that must be subsequently collected and transported to the treatment plants.

Subsequently, BMP tests were performed on bags to evaluate the feasibility and effectiveness of using an anaerobic process for their biodegradation (Dolci et al., 2021). The following tests were carried out under mesophilic conditions:

- tests series performed with a digestate from an anaerobic digestion plant that receives food waste contained only inside paper bags (*inoculum 1*);
- tests series performed with a digestate from an anaerobic digestion plant that receives food waste contained into bioplastic bags (*inoculum 2*).

This comparison was performed to evaluate differences in the results between inocula with a different acclimatisation to the examined substrates. As regards the substrates, one bioplastic shopper bag, one bioplastic dedicated bag, and one paper bag were manually cut in square pieces of 0.5 cm side. As regard the tests conditions, a food to microorganism ratio equal to 0.5 (in terms volatile solids - VS) was assumed. The tests were performed in 600 mL bottles; before the tests, a mineral medium containing macro and micro-nutrients was dosed and tap water was added to reach the desired working volume (450 mL). The tests were performed with the measurement of the generated methane by means of a volumetric system (Automatic Methane Potential Test System II, Bioprocess Control®).

Finally, a LCA was performed, according to the ISO standards (ISO 2018; ISO 2006), to evaluate the environmental performances of the overall food waste treatment chain comparing two systems characterised by

the use of paper and bioplastic collection bags.

The study was performed considering as functional unit (FU) the management of 1 kg of food waste generated (i.e. inserted into the collection bag) at the household.

The systems boundary included the production, packaging, and distribution of bags, the collection and transportation of bags containing food waste to the treatment plant, and the anaerobic digestion of food waste, including the management of all the treatment outputs, both useful (energy and compost) and residues sent to recovery or disposal. In particular, bioplastic bags cannot be generally treated by wet and semi-dry anaerobic digestion plants and therefore they are discarded before the digestion process. Moreover, due to their shape, there is a relevant dragging and unwanted removal from the treatment of food waste. On the contrary, paper bags removal before the digestion process is not required.

Two systems were modelled to consider the management of food waste collected inside paper or bioplastic bags. For bioplastic, both the use of dedicated and shopper bags was modelled.

The analysis was carried out examining 16 midpoint impact categories on the environment and the human health, evaluated at the midpoint level, with the impact indicator and the impact assessment models included in the Environmental Footprint method (Fazio et al., 2018).

The systems were modelled mainly according to primary data related to the Italian context (as regards the paper bag production, the food waste collection, and the food waste anaerobic digestion); inventory data of theecoinvent database (version 3.5 with the allocation, cut off by classification approach; ecoinvent centre, 2018) were used in support of the analysis.

As regards the modelling of the production and the end-of-life of the collection bags, two different approaches were considered for the management of recycling and recovery processes:

1. The approach applied in the International Environmental Product Declaration (EPD) System (EPD International, 2019) developed to enable and support organisations in any country to communicate quantified environmental information on the life cycle of their products in a credible, comparable, and understandable way. Accordingly, the polluter pays principle was used: the generator of the waste carries the environmental impact until the point at which the waste is transported to a scrapyards or at the gate of a waste processing facility (EPD International, 2019).
2. The approach that shall be applied in the Product Environmental Footprint (PEF) methodology in case of multi-functionality of products in recycling or energy recovery situation, as defined in the European Commission Recommendation 2013/179/EU of 9 April 2013 (EC, 2013) on the use of common methods to measure and communicate the life cycle environmental performance of products. In detail, the Circular Footprint Formula for materials (CFF) introduced and described in the Guidance for the development of Product Environmental Footprint Category Rules (PEFCRs; EC, 2018) was applied.

Results and Discussion

As regards the household storage tests, bioplastic and paper collection bags showed a different behaviour, with the paper allowing for higher weight losses: +29% and +44% on average compared respectively to bioplastic dedicated and bioplastic shopper bags (Figure 1) (Dolci et al., 2021).

In addition to the reduction of the amount of waste to be collected, paper bags allow for a lower odour and

leachate release during their use at the household, paving the way to a potential decrease of the frequency of food waste collection, thus reducing costs and environmental impacts.

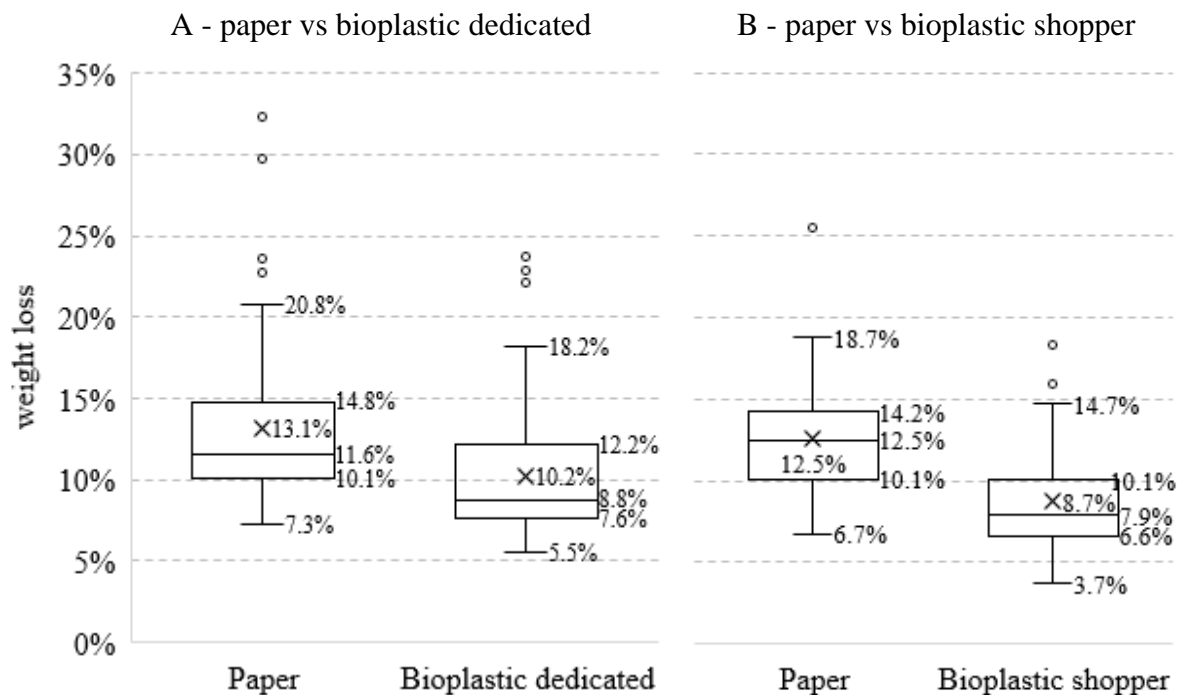


Figure 1. Household storage tests results: food waste weight losses in the time between the delivery in the bag by the user and the collection for the 59 comparative tests paper vs bioplastic dedicated bags (A) and the 53 comparative tests paper vs bioplastic shopper (B)

Concerning BMP tests, results are reported in Table 1. Focusing on the comparison between the two different bag typologies, the methane production for bioplastic resulted lower than that of paper by 70-80% in both tests series, with a bigger difference when paper is compared to dedicated bioplastic bags (Dolci et al., 2021).

Table 1. BMP test results (final BMP) referrer to the VS content of substrates: mean of the test in duplicate; standard deviation; comparison between bioplastic and paper bags

Test series	Substrate	Mean NmL CH ₄ /g VS	Standard deviation NmL CH ₄ /g VS	Bioplastic vs paper ($BMP_{bioplastic} - BMP_{paper}$)/ BMP_{paper}
<i>Inoculum</i> ₁	Bioplastic shopper	62.4	0.2	-72%
	Bioplastic dedicated	42.0	0.1	-81%
	Paper	225	27	-
<i>Inoculum</i> ₂	Bioplastic shopper	86.1	10.7	-68%
	Bioplastic dedicated	56.5	0.3	-79%
	Paper	272	5	-

As regards the LCA, Table 2 shows the potential impacts of the food waste management system based on paper bags, calculated with the EPD and the PEF approaches. Moreover, the impact changes in the system based on bioplastic bags (dedicated and shopper) are reported.

Globally, the comparison is less favourable to the paper bag system when the PEF approach is applied. This is mainly related to the fact that the PEF approach attributes to the recycled paper a relevant fraction of the impact for the production of the corresponding virgin fibres, whose manufacturing is more impacting than paper recycling.

Table 2. Potential impacts in the paper bag system and impact changes for the bioplastic bag system (dedicated and shopper) calculated with the EPD and the PEF approaches. Results are indicated per FU. *Impact change = (Bioplastic system-Paper system)/Paper system*

Impact category	EPD approach			PEF approach		
	Paper bag system impact	Impact change in the bioplastic bag system compared to the paper bag system		Paper bag system impact	Impact change in the bioplastic bag system compared to the paper bag system	
		dedicated	shopper		dedicated	shopper
Climate change (kg CO ₂ eq)	-5.99E-02	-24%	-1%	-5.73E-02	-11%	+9%
Ozone depletion (kg CFC-11 eq)	-6.49E-09	-45%	-7%	-6.25E-09	-28%	+7%
Ionising radiation (kBq U ²³⁵ eq)	2.81E-03	+150%	+91%	3.63E-03	+86%	+45%
Photochemical ozone formation (kg NMVOC eq)	2.50E-04	+14%	+2%	2.79E-04	0%	-10%
Respiratory inorganics (disease incidences)	3.39E-09	+19%	+5%	4.64E-09	-14%	-23%
Human toxicity, non-cancer effects (CTUh)	4.26E-09	+202%	+132%	1.33E-08	-4%	-26%
Human toxicity, cancer effects (CTUh)	6.16E-10	+68%	+52%	7.00E-10	+46%	+33%
Acidification (mol H ⁺ eq)	1.38E-04	+70%	+30%	2.04E-04	+10%	-14%
Eutrophication, aquatic freshwater (kg P eq)	5.38E-06	+78%	+35%	7.69E-06	+18%	-8%
Eutrophication, aquatic marine (kg N eq)	5.37E-05	+104%	+58%	6.06E-05	+77%	+38%
Eutrophication, terrestrial (mol N eq)	1.44E-03	+14%	+7%	1.65E-03	-2%	-7%
Ecotoxicity freshwater (CTUe)	4.22E-02	+109%	+66%	5.18E-02	+70%	+35%
Land use (Pt)	4.63E-01	+452%	+283%	5.20E+00	-52%	-66%
Water use (m ³ deprived)	6.70E-03	+1333%	+871%	1.85E-02	+430%	+255%
Resource use, energy carriers (MJ)	-8.21E-01	-32%	-6%	-7.86E-01	-19%	+5%
Resource use, mineral and metals (kg Sb eq)	1.55E-07	+22%	-20%	1.57E-07	+19%	-21%

Compared to the paper bag system, the bioplastic dedicated bag system causes an increase of the potential impacts (in the range +14% / +1333%) or a decrease of the benefits (when the impacts of the overall system are negative in sign) for all the examined categories.

When compared to bioplastic shopper bags, paper bags result better for 9 impact categories, while only for the Resource use, mineral and metals category the bioplastic bag resulted the best alternative (the differences are lower than 10% for the remaining 6 impact categories). Although the weight of the shopper bag is on average 39% higher than that of the dedicated bag, its use shows better environmental performances because only 50% of the impacts of its production, distribution, and end-of-life was given to the food waste management system under evaluation, according to the previous function as a shopping bag.

As regard the PEF approach, the bioplastic dedicated bag system, compared to the paper bag system, causes

an increase of the potential impacts (in the range +10% / +430%) or a decrease of the impacts negative in sign for 11 categories, while it results better than the paper bag system only for the Respiratory inorganics and the Land use categories. For the remaining 3 impact categories, the differences are lower than 10%.

Finally, when paper bags are compared to bioplastic shopper bags, the bioplastic bag system results better than that of paper for 6 categories and worse for 5 categories (the differences are lower than 10% for 5 categories).

Conclusions

The investigation of the performances of the different typologies of food waste collection bags (paper and bioplastic) showed significant differences in both the performed tests related to different stages of the organic waste management chain: the evaluation of the waste weight losses during the household storage and the mesophilic BMP tests showed a more favourable behaviour for the paper bags.

To complete the comparison between paper and bioplastic bags, new lab-scale tests under thermophilic conditions are currently in progress, including both BMP tests and semi-continuous co-digestion tests together with the food waste. Although BMP tests indicate a good degradability (>71%) of bioplastic bags under thermophilic conditions, semi-continuous co-digestion tests show a much lower degradability (<27%), confirmed by the observation of the undigested bag pieces. On the contrary, very interesting perspectives are offered by the paper bag, with a very high degradability in the semi-continuous co-digestion tests.

Globally, according to LCA results, the collection bag type has an important influence on the environmental performances of the entire food waste management system, with a beneficial influence associated with the use of recycled paper bags in place of bioplastic bags, in particular dedicated ones. Anyway, the comparison is influenced by the methodological approach used in the LCA modelling.

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