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DETERMINING FACTORS FOR THE PRESENCE OF IMPURITIES IN SELECTIVELY COLLECTED BIOWASTE

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ABSTRACT

The presence of impurities in biodegradable waste (biowaste) causes problems with the management of waste, among which are additional costs derived from the need to improve pre-treatment of biowaste, loss of treatment capacity and the difficulty selling treated biowaste as compost due to its low quality. When treated biowaste is used for soil conditioning it can also cause soil pollution. Understanding the reasons why impurities are in biowaste and the factors affecting the percentage of impurities present can be used to determine ways to minimise these negative effects. This paper attempts to identify the main causes for the presence of impurities in biowaste. In order to do so, it carries out an empirical analysis of the level of impurities in biowaste from municipal waste collection in two steps. First, a bivariate analysis focuses on significant correlations between the presence of impurities and several variables. Second, the construction of an explanatory model based on the significant relations obtained in the first step, and on literature research, are used to check the stated hypothesis. The estimates demonstrate that the collection system, the global levels of separate collection, the urban density of the municipality and the requirement to use compostable bags may be the main drivers of impurity levels in biowaste.

KEYWORDS

Biowaste, impurities, waste collection systems, separate waste collection, composting, soil conditioning.

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1. INTRODUCTION

The presence of impurities (non-biodegradable materials) in biowaste (in this paper considered as the separately collected organic fraction of municipal solid waste) hinders its recycling by increasing its treatment costs and negatively impacting the quality of the obtained product (Huerta *et al.* 2010), which in turn hinders its commercialisation. Some previous studies characterise and analyse biowaste collection (Gellens *et al.* 1995; Gomes *et al.* 2008; Hauer 2001), and one study analyzes the factors that affect the quality of biowaste (Alvarez *et al.* 2008). However, no studies thus far have constructed a model to explain the presence of impurities in biowaste. The difficulty of separating impurities from biowaste in an industrial process makes its treatment more expensive (Huerta *et al.* 2008a; Huerta *et al.* 2008b; Ruggieri *et al.* 2008). Moreover, there are evidences of the correlation between a high presence of impurities in biowaste and a high content of heavy metals in compost (Soliva *et al.* 2006, 2008), which can hinder its commercialisation.

This fact highlights the importance of understanding how the presence of impurities in biowaste changes under different contexts; for example, for different waste collection systems, or according to the socioeconomic characteristics of the population. Understanding these factors could facilitate the adoption of effective policies for improving the quality of biowaste, which in turn would make its treatment less expensive for public administrations and would improve the potential for safe application of treated biowaste in the soil. The latter would significantly improve greenhouse gas emissions of biowaste (Boldrin *et al.* 2006).

In an analysis of several compost samples, Soliva *et al.* (2006) found that samples presenting the highest percentage of heavy metals corresponded generally to high capacity composting plants (usually these plants treat biowaste from big cities, which could be a reason for the presence of more impurities compared to small capacity plants). Veeken and Hamelers (2002) and JRC (2008) pointed out that the origin of heavy metals in soil is their presence in compost. On the other hand, Huerta et al. (2008b) confirmed that plastic bags have a higher concentration of heavy metals than compostable bags, which suggests that biowaste delivered in plastic bags has a higher concentration of heavy metals than that delivered in compostable bags.

The studies referred to (Huerta *et al.* 2008b; JRC 2008; Soliva *et al.* 2006) point out several factors related to the collection system that could affect the presence of impurities, such as the use of compostable bags, the type of scheme used for the collection of biowaste or the size of the municipality. However, no studies have quantified the effects of these factors.

The objective of this study is to empirically check the hypothesis that the collection system, the levels of separate collection, and other socioeconomic factors such as the urban density and the use of compostable bags significantly affect the presence and level of impurities in biowaste, and to estimate the extent of this effect. In order to achieve this objective, a bivariate analysis has been done to identify bilateral relations among variables, and an explanatory model has been developed. The main difference with Alvarez *et al.* (2008) is the consideration of additional factors which affect the presence and level of impurities in the initial hypothesis, and the consequent increased complexity in our modelling methods used for verification. In contrast, Alvarez *et al.* (2008) only established correlations between the quality of biowaste and some socioeconomic variables, leading to sub-specification problems when analysing estimators.

Material and methods used are described in section 2. Section 3 includes bivariate analyses between variables and the development of the regression model. Finally, section 4 presents the conclusions arising from the study.

2. MATERIALS AND METHODS

This section presents the research methodology used in this article. First, a description of the different information analysed is provided, along with the different sources. Second, the official methodology for the characterisation of the presence of impurities in biowaste is presented. Finally, the statistical methodology used for the analysis of the different data is described.

Data and sources

The study used data available for Catalonia which is one of Spain's autonomous regions. Catalonia has a population of 7.5 million inhabitants (2011), and has its own waste regulation within the framework of the Spanish legislation. Collection of waste is carried out primarily by local authorities. Biowaste is collected separately in most of the region and is processed to create compost or treated in mechanical-biological treatment facilities.

Quarterly data for the period 2006-2008 of biowaste collection characterisations was provided by the Catalan Waste Agency (ARC). These data comprise 301 biowaste collection circuits. The number and periodic nature of the characterisations performed make this dataset unique worldwide (very few comparable datasets in terms of completeness and time scope are available). However, the fact that some circuits include several municipalities has limited the analysis, since in these cases the values provide an average of all municipalities included in the collection circuit. Due to this, only disaggregated data (available for 213 municipalities) has been included in the analysis.

In addition, ARC provided data for the biowaste collection system applied in each municipality for each type of collection. Collection systems were classified as either bring schemes or door to-door schemes. Bring schemes were further classified as one-fraction containers (hereafter referred to as single-fraction containers), two-fraction containers (containers with separate compartments for biowaste and refuse), and underground containers (single-fraction containers placed underground). Door-to-door collection schemes were classified based upon the number of fractions collected (from two to five fractions).

The Catalan Institute of Statistics (IDESCAT) provided data on population, urban density (population divided by urban area) and the percentage of vacation households for each municipality. It also provided data on household disposable income (GDHI) for municipalities with over 5,000 inhabitants.

This dataset is much more complete than the one used by Alvarez *et al.* (2008), in which only data from one year was taken into account.

Methodology of waste characterisations

ARC sets a protocol to undertake the waste characterisations of biowaste (Agència de Residus de Catalunya 2010). The time between reception of the material and characterisation must not exceed 24 hours during the summer and must not exceed 48 hours the remainder of the year. The analytical protocol is summarised in the following steps:

- Collected biowaste is homogenised in order to ensure a representative sampling.
- Before sampling, bulky waste is manually separated and weighted.
- The sampling is divided into four quarters. Two diagonally opposed quarters are selected, and the material is homogenised again. This operation is repeated until a representative sample of approximately 250 Kg finally remains.
- Once the sample has been obtained, the material is separated in two different fractions. The objective is to separate the compostable fraction from impurities, and to classify impurities into different sub-fractions. The compostable fraction includes:

1. Biowaste: food leftovers (fruit, vegetables, meat, bones, fish, shellfish, molluscs, eggshells, nuts, bread, coffee, tea), dirty paper towels, dirty paper napkins, tissue paper, cork, sawdust, small plant remains, small natural wood materials, animal excrements (without absorbent materials), compostable bags and other compostable materials.
2. Green waste: remains from gardening and pruning (larger size and more woody type) and large natural wood materials.

The impurities fraction or non-compostable fraction includes the rest of the materials, which are classified into 11 sub-fractions (see details in Figure 2).

Once the sample is separated, every sub-fraction is identified and weighed to obtain the overall percentage presence of impurities and the percentage of impurities for each of the different sub-fractions. In order to make the sample comparable, impurities for 2006 have been adjusted for moisture content (to consider water in these fractions as biowaste, not as an impurity). This was necessary because the method for 2007 and 2008 was changed to include the application of a moisture content correction factor to paper and cardboard, and to plastic bags.

Methodology of the data analysis

In order to determine the effects of the collection system, the global levels of separate collection, the use of compostable bags, and other socioeconomic variables on the level of impurities, a two-step approach was used.

First, a statistical descriptive analysis of the variables was conducted. This included a bivariate analysis focused on several significant correlations between the relevant variables (section 0).

Second, an explanatory model was constructed, based upon the significant relations obtained in the first step, to check the stated hypothesis (section 3.2). The model was obtained by regression analysis, using the Ordinary Least Squares (OLS) method.

Descriptive analysis of data

This section provides a descriptive analysis of the situation in relation to the presence of impurities in biowaste from separate municipal waste collection in Catalonia. It also analyses some other related variables.

Figure 1 shows the mean results of the biowaste characterisations considered in the study.

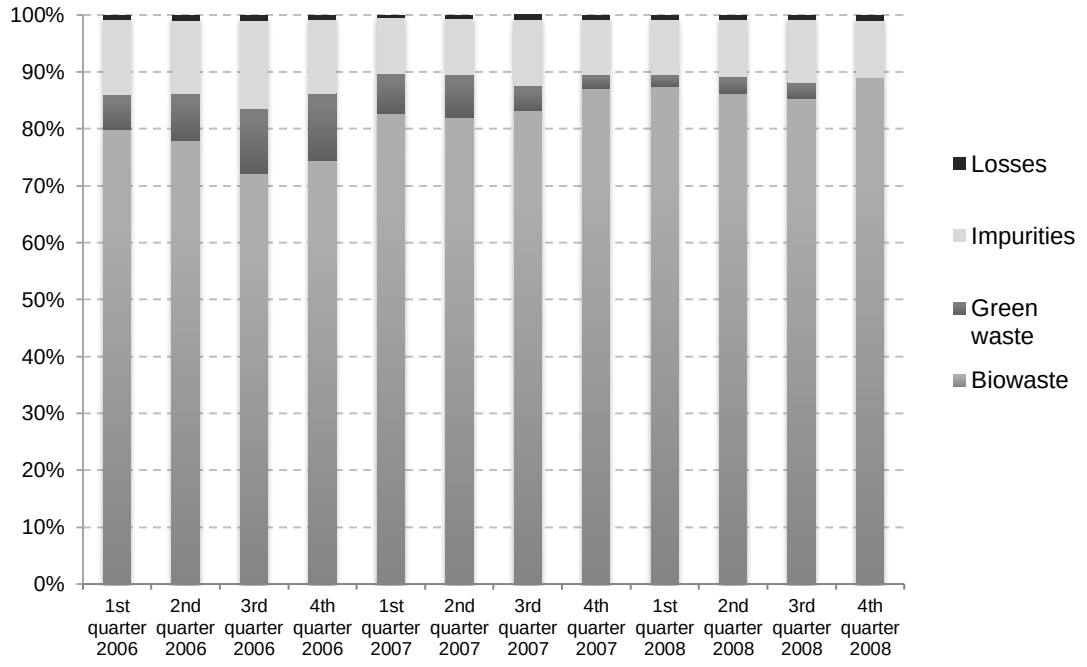

Figure 1. Arithmetic mean of biowaste composition in Catalan collection circuits, 2006-2008. Note: Percentages based on weights. "Losses" refers to the losses of material produced during the characterisations.

The average value of the impurities fraction for the entire period is 11.38% (as an indication, a value of 10% of impurities is considered the maximum recommended to obtain a quality compost; Huerta *et al.* 2008a). This suggests that compost resulting from the treatment of biowaste may have a lower than desired quality.

Figure 2 shows the relative weight of each component within the impurities fraction during the entire period (calculated as the arithmetic mean of all characterisations). It should be noted that plastics, plastic bags and paper/cardboard are the materials with the highest percentage of biowaste impurities, irrespective of the period considered. This suggests that the use of compostable bags for the delivery of biowaste may be one of

the factors affecting the presence of impurities, as pointed out also by Martin (2008). Since most of the impurities are waste fractions that could have been recycled (i.e., plastic, metals, glass, paper), this suggests that the collection system (and in particular the incentives created by the collection system for waste separation) may also be a key factor for the presence of impurities in biowaste.

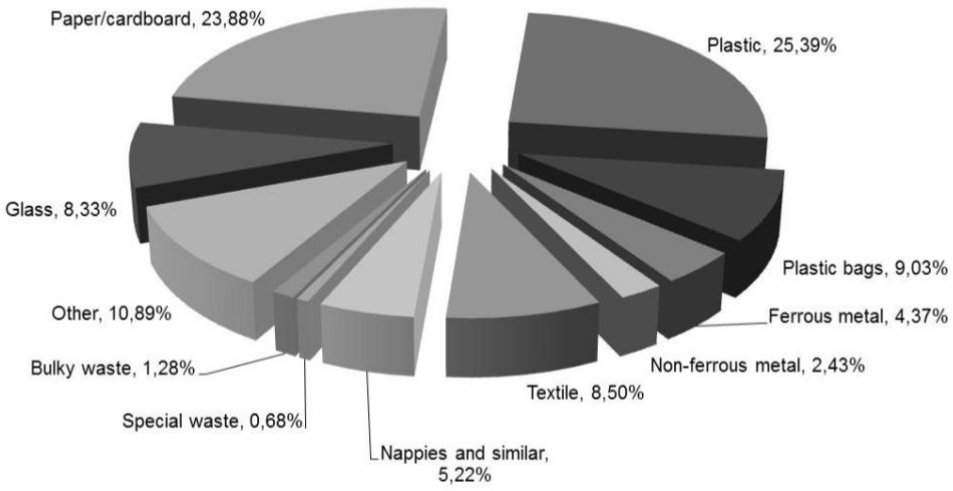

Figure 2. Composition of impurities fraction in biowaste from Catalan municipalities, 2006-2008 (percentages based on weight).

3. RESULTS AND DISCUSSION

This section describes the results from the statistical and regression analysis.

3.1. Bivariate analysis

By means of a bivariate analysis, this section seeks to identify possible cross-relationships between different variables that affect the presence and composition of impurities within separately collected biowaste in Catalan municipalities.

Relationship between the collection scheme and the percentage of impurities

Waste collection schemes used by each municipality may be a key factor to explain the percentage of impurities in biowaste. In Catalonia, most of the population is served by a bring collection scheme, where containers for the separate collection of biowaste are placed in the street (either above the ground or underground) together with containers for other waste fractions. But there is a growing number of municipalities that have implemented door-to-door separate waste collection schemes, where biowaste is collected individually from each user according to a pre-defined schedule and waste is delivered directly in bags or boxes at the doorstep. In 2008, the percentage of analysed municipalities that had a door-to-door

collection scheme was 11.6%, whereas the rest of the municipalities (88.84%) were using a bring collection scheme. Door-to-door collection schemes create a greater incentive for separate collection, since waste that is not properly separated is not collected. This avoids the collection of other fractions that are considered as impurities, so that door-to-door schemes are expected to present lower levels of impurities in biowaste than bring schemes.

Table 1 presents the weighted average of impurities on the total amount of biowaste collected for the two main types of collection systems.

Table 1. Weighted average of percentage (in weight) of impurities in biowaste depending on the waste collection system in Catalonia, 2006-2008.

Collection system	**2006**	**2007**	**2008**
Door-to-door schemes	7.70%	7.32%	8.23%
Bring schemes	22.36%	14.99%	16.34%
Total	**20.60%**	**14.92%**	**16.25%**

Note: Averages have been weighted by tons of collected biowaste in each municipality.

Source: Own elaboration based on data from ARC.

Table 1 shows that, as expected, door-to-door schemes present substantially lower levels of impurities than other collection schemes. It also shows that the averages of the impurities fractions decreased from 2006 to 2007, but then increased from 2007 to 2008 (according to Alvarez *et al.* (2008), in 2004 the weighted mean of impurities in Catalonia was 22% by weight).

Bring and door-to-door collection schemes can be implemented in several forms. In the case of door-to-door schemes, four sub-schemes can be identified according to the number of fractions that are collected door-to-door. The most common scheme is four fractions, where only glass is collected in containers and biowaste, packaging waste, paper/cardboard and refuse are collected door-to-door. However, there are also two-, three- and five-fractions schemes. In this case, a higher number of fractions collected door-to-door encourages greater waste separation by households, and lowers the presence of impurities expected to be found in biowaste.

Bring schemes can be identified with the following sub-schemes: single-fraction containers (single-fraction containers placed on the streets, the most common container), two-fraction containers (which allow the delivery of biowaste and refuse in the same container) and underground containers (single-fraction containers placed underground). Two-fractions containers are expected to have high levels of impurities, since it is more likely that a user will deliver refuse in the compartment for biowaste than it is for single-fraction containers. For underground containers there is no theoretical basis that allows an ex-ante evaluation.

Table 2 shows the arithmetic mean of the percentage of impurities in municipalities for the different sub-types of separate waste collection schemes for the period 2006-2008. Only those circuits where all municipalities have the same collection system have been included in the analysis.

Table 2. Arithmetic mean of percentage (in weight) of impurities in biowaste, for different waste collection schemes, 2006-2008.

Collection system		Number of circuits	2006	2007	2008
Door-to-door schemes	2 fractions	36	8.17%	7.82%	8.49%
	3 fractions	9	3.96%	3.38%	3.83%
	4 fractions	73	4.40%	3.58%	2.86%
	5 fractions	26	10.75%	8.20%	10.07%
	TOTAL	**144**	**6.46%**	**5.71%**	**5.79%**
Bring schemes	Single-fraction containers	392	9.75%	8.84%	9.08%
	Two-fraction containers	4	28.03%	16.49%	12.79%
	Underground containers	12	23.52%	23.21%	21.63%
	TOTAL	**408**	**10.34%**	**11.07%**	**11.61%**

Note: total sample: 552 circuits.

Source: Own elaboration based on data from ARC.

Table 2 shows that municipalities with two-fraction containers and underground systems are those with a higher percentage of impurities. Among municipalities with door-to-door systems, those collecting five fractions separately are the ones with the higher percentage of impurities, contrary to what was expected. However, very few observations of these three collection systems (two-fractions containers, underground containers and 5-fraction door-to-door collection schemes) are available.

Note that the results presented in Table 2 (weighted average) are higher than those in Table 3 (arithmetic mean). The cause may be that larger municipalities tend to present higher levels of impurities due to several factors, such as more difficulty controlling larger, more complex organizations.

From Table 2 and Table 3 it can be concluded that biowaste collected by means of door-to-door schemes has fewer impurities, on average, than that collected by means of other collection systems. This indicates that the collection scheme is one of the factors affecting the presence of impurities in biowaste.

Incidence of the use of compostable bags on the presence of impurities

Due to the importance of plastic bags and their effect on impurities in biowaste (see Figure 2), the impact of the promotion and compulsory use of compostable bags in municipalities has been analysed. Martín (2008) suggests that its use may have a positive effect in reducing the levels of impurities. Alvarez *et al* (2008) did not consider this factor, probably due to the lack of data available at the time of their study.

Data needed for an analysis of municipalities based upon whether the use of compostable bags for the collection of biowaste is mandatory, recommended or neither mandatory nor recommended is available. 139 of these municipalities do not share the biowaste collection circuit with other municipalities and, therefore,

the effect of the promotion of compostable bags can be isolated. Table 3 shows the average of impurities in municipalities of Catalonia based on this analysis.

Table 3. Incidence of the use of compostable bags on the presence of impurities, 2006-2008

Use of compostable bag	Arithmetic average of impurities (% in weight)		
	2006	2007	2008
Compulsory	2.17	1.98	1.61
Recommended	9.97	8.77	9.37
Neither compulsory nor recommended	12.22	10.85	10.93

Note: total sample: 139 municipalities.

Source: Own elaboration based on data from ARC.

From Table 3, it can be concluded that on average the presence of impurities in biowaste is much lower in municipalities where the use of compostable bags is mandatory. Levels are also slightly lower in municipalities where the use of compostable bags is recommended than it is in municipalities where its use is neither compulsory nor recommended. Since plastic bags are one of the most important elements within impurities (as mentioned above), an extensive introduction of compostable bags may substantially reduce impurity levels in biowaste. Furthermore, since compostable bags are translucent, it is easier for waste collectors to visually detect the presence of impurities and reject the collection of those bags that include a high level of impurities.

Beyond the direct effect of compostable bags on the level of impurities, the mandatory use of these bags also indicates a high level of environmental commitment from the municipality, which may be translated into other aspects that also affect the level of impurities (such as environmental awareness of the population). In fact, in the great majority (all except one) of the municipalities analyzed where the use of compostable bags is obligatory or promoted, separate waste collection is performed by means of a door-to-door scheme. As seen above, this factor is also crucial to a low level of impurities.

3.2. Regression analysis

This section contains the specification of an explanatory model which is then used to estimate effects of various factors on impurities in biowaste. The model attempts to contrast the hypothesis that explanatory variables affect the level of impurities in biowaste and to quantify the intensity of this effect.

Data for 2006 has been used to perform the regression analysis. Municipalities selected for the analysis were those that did not share the biowaste collection circuit with other municipalities, so that the problems that would be related to assigning an average level of impurities to each of the municipalities of the circuit are avoided.

The following model has been specified to explain the different level of impurities in biowaste selectively collected by Catalan municipalities. This specification is based on literature and on the statistical and correlational analysis done in the first step of the research. As shown in previous section, from empirical

evidence and from statistical analysis, the type of collection scheme and the use of compostable bags may have an influence on the presence of impurities in biowaste. Furthermore, there are a set of socio-economic factors including percentage of total selective collection and disposable household income urban density of municipality that may capture other social and cultural aspects that produce different results among municipalities. Those variables are considered as control variables in the model, since they are not the main variables in the estimations.

Eq. 1

$$\ln(imp_i) = \alpha + \beta_1 dtd2 + \beta_2 norm_i + \beta_3 und_i + \beta_4 sc_i + \beta_5 gdhi_i + \beta_6 dens_i + \beta_7 bag + u_i$$

where *imp* is the percentage of impurities in biowaste collected in municipality *i*; *dtd2* is a dummy variable that takes the value 1 if municipality *i* performs door-to-door collection of more than two fractions and 0 otherwise; $norm_i$ takes the value 1 if municipality *i* collects waste with single-fraction containers and 0 otherwise; und_i takes the value 1 if municipality *i* collects waste with underground containers and 0 otherwise; sc_i is the percentage of total selective collection in municipality *i*; gdh_i is the average disposable household income in municipality *i* (in 2006 monetary units); $dens_i$ is the urban density of municipality *i* (total population divided by urban area, in square meters), bag_i takes the value 1 if the use of compostable bags is compulsory in municipality *i* and 0 otherwise; and u_i is the error term.

The Ordinary Least Squares Method was used to derive the model; results from the model are shown in Table 4.

Table 4. Variables of the explanatory model of the presence of impurities in separately collected biowaste.

Ordinary Least Squares (OLS)

Dependent variable: Ln(imp)

Included observations: 97 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
dtd2	-0.3635	0.1657	-2.1931	0.0309
norm	-0.1938	0.0822	-2.3575	0.0206
und	1.1866	0.3823	3.1040	0.0026
sc	-0.0084	0.0026	-3.2841	0.0015
gdhi	$2.86*10^{-8}$	$1.82*10^{-8}$	1.5682	0.1204
dens	-4.3617	1.6094	-2.7101	0.0081
bag	-1.8023	0.3049	-5.9115	0.0000
α	2.8492	0.1124	25.3505	0.0000

R-squared	0.6095	Mean dependent variable	2.3152
Adjusted R-squared	0.5788	S.D. dependent var.	0.5691
S.E. of regression	0.3693	Akaike info criterion	0.9247
Sum squared resid.	12.1413	Schwarz criterion	1.1371
Log likelihood	-36.8494	F-statistic	19.8491
Durbin-Watson	1.4935	Prob. (F-stat.)	0.0000

Although the number of independent variables is high, most of them are individually significant. There is also joint significance.

All estimations shown in Table 4 have the expected sign. An increase in those variables whose coefficients have a positive sign produces an increase in the percentage of impurities in biowaste; for those variables with negative coefficients, a decrease in the percentage of biowaste occurs. Almost all variables are significant at 95%, except for disposable household income which is significant at 88%. The overall adjustment of the regression provides an adjusted R-squared value of 0.58. This means that the exogenous variables explain about 58% of the variability of the endogenous variable (level of impurities).. The other estimators do not show significant problems in the estimations. Those estimators suggest that, even when disposable income is not considered, the result of estimates would not change significantly, that is, disposable income does not seem to be an important factor explaining the model, but the estimations suggest that this variable may have little impact to not reject it.

According to the model, the higher the selective collection rate, the lower the presence of impurities. This result could suggest that a higher selective collection rate reflects a higher level of citizen's awareness, which in turn results in a lower presence of impurities. This can also explain why the global presence of impurities decreases over time (as more awareness campaigns are carried out).

Besides, municipalities with separate door-to-door collection schemes of more than two fractions have lower impurity levels than those with other systems.

On the other hand, the higher the disposable household income of the municipality, the higher the level of impurities in biowaste. In this case, a higher presence of impurities could be explained by an overall higher generation of waste in those municipalities with a higher income, and particularly from a higher generation of packaging waste, as Mazzanti and Zoboli (2008) point out. Also, greater urban densities result in lower percentages of impurities, although no explanations have been found for this behaviour.

As expected, the compulsory use of compostable bags for the collection of biowaste results in lower levels of impurities.

Even though there is limited empirical literature on this specific issue, the results are consistent with some of the theoretical literature that points out the fact that the collection system, the global levels of separate collection, and other socioeconomic variables, such as the urban density of the municipality and the requirement to use compostable bags, affect the levels of impurities. However, the conclusions are different from those provided by Alvarez *et al.* (2008), the only other study to analyse factors affecting the presence and level of impurities in Catalonia. The differences are mainly due to the consideration of limited factors (omission of relevant variables) in their specifications that lead to biased estimators and due to the smaller dimension of their samples.

This model would allow ex-ante estimations of the levels of impurities expected in new implementations of separate collections of biowaste, assuming that certain basic aspects of the collection systems were defined. These estimations would be useful when designing and budgeting treatment facilities for separately collected biowaste.

4. CONCLUSIONS

Theoretical literature suggests some key factors affecting the presence and level of impurities in biowaste. However, there are no studies that have constructed a model to explain these factors. This is primarily due to the lack of available data necessary to conduct such analyses, which in turn can result from the cost of conducting biowaste characterisations.

Bivariate analysis carried out in this article to identify cross-relationships between variables shows that waste collection schemes are a key factor in explaining the percentage of impurities in biowaste. Door-to-door collection schemes achieve the lowest average levels of impurities. Compulsory use of compostable bags is also identified as a key factor affecting the presence of impurities in biowaste..

The purpose of the model built in this article is to obtain empirical evidence pertaining to the factors contributing to impurities in biowaste that are reported in the literature. The factors reported there are confirmed by the bivariate analysis; in addition, this analysis points out other significant factors, such as the

collection rate and the average disposable income. … In turn, this could contribute to the design of better treatment facilities and the identification of policies
for the reduction of impurities in biowaste.

The research conducted in this paper has important implications for waste policy. Although more empirical evidence is needed in this area, it has been shown that door-to-door schemes, the type of containers used and the compulsory use of compostable bags are key elements in reducing the presence of impurities in biowaste.

The paper also shows that there are some socio-economic factors (such as the disposable income) that affect the level of impurities. These factors are not under the control of waste authorities. Therefore, to a certain extend, waste facilities have to be adapted to receive different levels of impurities, which might also fluctuate over time.

Despite the fact that the article is based on data from a single region, the number of observations available, together with the completeness and periodicity of the dataset, provide general relevance to the results obtained.

Besides the relations directly extracted from the estimates, other aspects may also affect the level of impurities. Among others, these might include the amount of public resources allocated by government campaigns to raise environmental awareness among the citizens, the size of the opening of the containers (in the case of container-based collection schemes) or the tariff structure of biowaste treatment plants (which in most cases varies according to the amount of impurities). However, there is a lack of data to evaluate the possible effects of these factors in a quantitative way.

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