LIFE BIOBEST

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LIFE BIOBEST

GUIDING THE MAINSTREAMING OF BEST BIO-WASTE RECYCLING PRACTICES IN EUROPE

D2.2: Statistical analysis regarding bio-waste collection data in relation to socio-economic parameters

WP2: Definition of bio-waste indicators and data analysis

T2.3: Statistical analysis of existing databases

APRIL **2025**

Public Report

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1 Document attributes

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1.1 Document Management Control Sheet

Table 1. Document Management Control Sheet

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1.2 Document Revision History

Table 2. Document Revision History

Version Number	Date	Version	Short Description of the Changes	Editor
0.1	02/04/24	1st Draft	Document created as 1st version	ENT – L. Campos, F. Navarro
0.2	05/10/24	2nd Draft	Document created as 2nd version	ENT – L. Campos, F. Navarro, G. Nohales
0.3	18/11/24	3rd Draft	Document created as 3rd version to be distributed	ENT – L. Campos, F. Navarro, Gemma Nohales, M. Stinavage CIC-M. Giavini
0.4	04/12/24	4th Draft	Peer reviewers' contributions in track changes	CIC and ACR+ ENT
0.5	31/03/25	5th Draft	Revision to include peer reviewers' contributions and result comm. sections. Linguistic and format revision	ENT – Mike Stinavage, Gemma Nohales
0.6	02/04/25	6th Draft	Final updates and checks	ENT – Luis Campos, Francisco Navarro, Gemma Nohales CIC-Michele Giavini
0.7	24/04/25	Definitive/ Approved	Final linguistic and format revision Definitive and approved version to be submitted	ENT – Mike Stinavage, Gemma Nohales
0.8	30/04/25	Submitted	Submitted to Participant Portal in PDF	ENT - Gemma Nohales

1.3 Table of Acronyms

Table 3. Table of Acronyms

Acronym	Term
AD	Anaerobic digestion
BP	Best practice
D	Deliverable
DtD	Door-to-door
EC	European Commission
EoW	End of Waste
EU	European Union
GW	Garden waste
Ho.Re.Ca.	Hotels, restaurants and cafeterias
inhab.	inhabitant
KPI	Key performance Indicator
km	kilometre
KW	Kitchen waste
LD	Landfill Directive
MS	Member State(s)
n.d.	No data
res.	Residential
RW	Residual waste
yr	year

1.4 LIFE BIOBEST Project Summary

EU obligations on the selective collection of bio-waste came into force at the end of 2023, increasing the availability of source-separated bio-waste for composting and anaerobic digestion. To ensure the development of bio-waste management best practices and the production of quality compost and digestate for soil applications, while minimising any negative effect and closing effectively the loop, a comprehensive analysis is required regarding bio-waste management strategies, instruments and management schemes and their results given that large disparities exist among experiences in the EU.

The LIFE BIOBEST project aims to identify and validate the current Best Practices (BP) and management instruments along the bio-waste management chain (from generation to treatment) that allow the production of quality compost and digestate and establish a series of reference Key Performance Indicators (KPI), based on the analysis of existing databases and experiences. In a policy brief about barriers and through interconnected co-creation meetings with relevant expert stakeholders of the sector, solutions have been provided to overcome the identified technical, regulatory, economic and environmental barriers to widely adopt the proposed BPs.

Four guidelines and a comprehensive EU-wide guide have been created, together with two decision-support tree guides for local and regional authorities to adapt bio-waste management models to their specific context, offering feasible BP and management instruments to promote efficient collection and subsequent recycling of bio-waste into quality compost and digestate.

By means of an analysis of the input materials, treatment practices, resulting compost and digestate quality, a proposal for premium European standards for biological waste entering composting and anaerobic digestion have been developed with the ultimate goal of promoting the certification of these materials and treatments, guaranteeing optimal management processes and a safe, beneficial return to the soil.

The outcomes of LIFE BIOBEST will promote a significant improvement of the collection and treatment systems, and consequently of the quantity and purity of the input material, reducing process rejects and favouring the conversion of bio-waste into high-quality compost and digestate.

The LIFE BIOBEST consortium is led by Fundació ENT (ENT) in partnership with Consorzio Italiano Compostatori (CIC), ACR+ (Association of Cities and Regions for sustainable Resource management), European Compost Network (ECN) and Zero Waste Europe (ZWE). It is a 2.5-years LIFE Preparatory Project funded by the European Commission.

Project Total Eligible Costs: € 1,664,600.07, Funding Rate: 90%, Maximum Grant Amount: € 1,498,140.05.

2 Executive summary

This study focuses on the analysis of the factors that influence the collection per capita of kitchen waste and bio-waste based on data from municipalities in Catalonia and Italy between 2010 and 2021. These are the only areas in EU in which open data is available at municipal level and differentiated between kitchen waste and garden waste and the only obtained data from the previous LIFE BIOBEST Task 2.1. A regression analysis, a statistical technique used to estimate the impact of various waste management variables, as well as socio-economic and demographic variables (independent or explanatory variables), on the kitchen waste and bio-waste collection per capita (dependent or explanatory variables), has been conducted. Table 4 lists the variables used in the statistical analysis. Detailed information about these variables can be found in section 3.

Table 4. Variables used in the statistical analysis for Catalonia and Italy

Category	Variable	Description	Catalonia	Italy
Dependent variable				
Waste management	Collection of kitchen waste per capita	Corresponds to the collection of kitchen waste (in kg/inhabitant/year).	✓	✓
	Collection of bio-waste per capita	Corresponds to the sum of kitchen waste separately collected and garden waste collected (in kg/inhabitant/year). See more details in section 3.	✓	✓
Independent variables				
Territory	Elevation	Average elevation of the municipality in meters.	✓	-
	Area	Area of the municipality in km^2.	✓	✓
	Coastal municipality	Dummy variable that assumes the value "1" when the municipality is in a coastal area, and "0" otherwise.	✓	-
Demography and population	Population	Number of inhabitants.	✓	✓
	Population (municipalities w/ ≤5,000 inhab.)	Dummy variable that takes the value “1” when the municipality falls within this population level, and “0” otherwise.	✓	✓
	Population (municipalities w/ 5,001 to 50,000 inhab.)		✓	✓
	Population (municipalities w/ ≥50,000 inhab.)		✓	✓
	Population density	Number of inhabitants per km^2.	✓	✓
	Foreign population	% of foreign inhabitants over the whole population.	✓	✓
	Average age of the population	Average age of the population.	✓	✓

Category	Variable	Description	Catalonia	Italy
	Ageing index	Number of elderly population (aged 65 years and over) per 100 inhabitants. In Catalonia, the indicator compares the elderly population with the total population, while in Italy, the comparison is made with those younger than 14 years old.	✓	✓
	Young age dependency ratio	Number of young people (aged 15-29 years) per 100 inhabitants. In Catalonia, the indicator compares the number of young people with the total population, while in Italy, the comparison is made with the number of people of working age (i.e., 15-64).	✓	✓
Education	Population with only primary education	Population aged 15 or over with only primary education.	✓	-
	Population with tertiary education	Population aged 15 or over with tertiary education.	✓	-
	Lower secondary education	Population aged 25-64 with an educational qualification no higher than lower secondary education (%).	-	✓
Economy and living conditions	Taxable income	This represents the total income after deductions, measured in millions of euros.	-	✓
	Average net income per person	Average net income per person, measured in Euros per capita.	✓	✓
	Average net income per household	Average net income per household.	✓	-
	Unemployed population	Proportion of unemployed population over the population aged 16 to 64 (in %).	✓	-
	Unemployment rate	The percentage of the population aged 15 years and over who seek employment compared to the total population in the same age group.	-	✓
	Employment rate	Percentage of employed individuals aged 20-64 compared to the total population of the same age group.	-	✓
	Gini index for inequality	The index ranges between 0 (maximum equality) and 100 (maximum inequality).	✓	-
Tourism	Total accommodations	Corresponds to the sum of accommodations (e.g., hotels, camp sites). There may be minor differences in the types considered in the two study areas.	✓	✓
	Total accommodations per 1,000 inhabitants	Corresponds to the sum of accommodations per 1,000 inhabitants. There may be minor differences in the types of accommodation considered in the two study areas.	✓	✓
	Total nights at accommodations	Total number of nights at tourist accommodations, hotels and similar establishments, and other accommodations.	-	✓
	Total nights at accommodations per 1,000 inhabitants	Total number of nights at tourist accommodations, hotels and similar establishments, and other accommodations per 1,000 inhabitants.	-	✓

Category	Variable	Description	Catalonia	Italy
Waste management	Impurities	% of impurities found in bio-waste (no detailed data at municipal level for Italy).	✓	
	Bio-waste treated in home composting	This data is based on estimates.	✓	
	Garden waste	Biodegradable material such as leaves and branches, usually generated from gardening for the maintenance of green spaces.	✓	✓
	Collection model	Type of collection models implemented: i) For Catalonia it corresponds to door-to-door (DtD); open waste containers and containers with controlled access; ii) For Italy, it corresponds to DtD; street containers with controlled access; building community waste bins; street open waste containers; and mixed collection (combination of the other systems).	✓	✓
	Door-to-door collection model	Dummy variable that assumes the value "1" when the municipality has a DtD system, and "0" otherwise.	✓	✓
	Door-to-door collection model coverage	% of population covered by a DtD collection model.	✓	-
	Open waste bins	Dummy variable that assumes the value "1" when the municipality has a collection model based on open waste bins, and "0" otherwise.	✓	✓
	Containers with controlled access	Dummy variable that assumes the value "1" when the municipality has a collection model based on containers with controlled access, and "0" otherwise.	✓	✓
	Mixed collection	Dummy variable that assumes the value "1" when the municipality has a model based on mixed collection (DtD and open waste bins), and "0" otherwise.	-	✓
	Collection costs for mixed waste	Collection costs paid by the local authorities, expressed in Euros per capita for the residual/mixed waste fraction.	-	✓
	Collection costs for separate waste fractions	Collection costs paid by the local authorities, expressed in Euros per capita for the recyclable fractions (aggregated).	-	✓
	Total collection and treatment costs	Collection and treatment costs (aggregated) but excludes revenues from dry recyclables sales. Data is expressed in Euros per capita.	-	✓

Legend: The signs "✓" and "-" indicate whether the variable was or was not available in the corresponding study area, respectively, according to the data availability for each case.

Note: Further details on the analysis period and the sources of the variables are available in section 5.

For the statistical analysis, models have been developed with panel data, which allow an examination of the relationships between variables in multiple municipalities over time. Additionally, in each territory the effects of these variables on the collection of bio-waste have been estimated for all municipalities, solely for 2021. Cross-sectional models are used for this analysis since both a larger number of municipalities can be included and there are more data points available in 2021. In addition, cross-sectional models evaluate variables for which there is only data for 2021, such as most of the variables referring to waste management.

In general, the models estimated for both territories show that the independent variables only explain part of the variability in the per capita collection of kitchen waste and bio-waste (the analysis demonstrates that there is a robust causal correlation between variables of the study). This suggests that there are probably relevant factors that have not been considered in the statistical analysis. Waste management is a complex system with many other elements or conditions that may influence it (e.g., municipal policies, available budget, availability of financial aid, knowledge of technical personnel, etc.). Despite this, the validity of the independent variables' estimated effects on the collection per capita is not compromised.

Another important factor to understand the differences regarding the results for kitchen waste and bio-waste is that bio-waste includes amounts of garden waste fraction. This can result in a greater variability of generation throughout the year and by type of municipality based on weather conditions, public gardens, quantity of single-family homes with gardens, etc.

2.1 Main results from Catalan analysis

In the case of Catalonia, all estimates are made for the collection per capita of kitchen waste and bio-waste for all municipalities and, separately, for those with a population of less than 5,000 inhabitants.

Table 5 presents a summary of the results obtained, for the different types of estimated models (with panel data and cross-sectional data), regarding the incidence of the analysed variables on kitchen waste and bio-waste collection per capita for Catalonia. To improve clarity in the presentation of the results, it is indicated for each independent variable whether its estimated impact on collection is high, medium or low intensity. The intensity of the effect reflects the degree of impact that each independent variable has on per capita collection. This is measured by the numerical value associated with each independent variable, also known as the coefficient value, in a regression equation (for more information, see section 5). It is also indicated whether this effect is generated in the same direction, that is, if an increase in the independent variable generates an increase in collection (+ sign in the value) or vice versa (- in the value).

Table 5. Main results of the optimal models of each type of analysis carried out for Catalonia

Dependent variables	Independent variables	Models with data panel		Models with cross-sectional data	
		All municipalities	Municipalities with <5,000 inhab.	All municipalities	Municipalities with <5,000 inhab.
Period		2010-2021		2021	
Collection of kitchen waste (kg/inhab./yr)	Area	*n.d.*	*n.d.*	+	-
	Population	*n.d.*	*n.d.*	++	++
	Population (municipalities w/ ≤5,000 inhab.)*	*n.d.*	*n.d.*	++	*n.d.*
	Population (municipalities w/ 5,001 to 50,000 inhab.)*	*n.d.*	*n.d.*	++	*n.d.*
	Population (municipalities w/ ≥50,000 inhab.)*	-	*n.d.*	*n.d.*	*n.d.*
	Population density	-	+	-	*n.d.*
	Average age of the population	++	+	++	++
	Population with only primary education	+	*n.d.*	*n.d.*	*n.d.*
	Average net income per person	++	+	*n.d.*	*n.d.*
	Unemployed population	*n.d.*	*n.d.*	-	-
	Gini index for inequality	*n.d.*	-	*n.d.*	*n.d.*
	Total accommodations per 1,000 inhab.	---	--	-	-
	Door-to-door collection model*	+++	+++	+++	+++
	Containers with controlled access*	*n.d.*	*n.d.*	++	++
Collection of bio-waste (kg/inhab./yr)	Area	*n.d.*	*n.d.*	-	-
	Population (municipalities w/ ≤5,000 inhab.)*	+++	*n.d.*	+	*n.d.*
	Population (municipalities w/ ≥50,000 inhab.)*	---	*n.d.*	*n.d.*	*n.d.*
	Population (municipalities w/ 5,001 to 50,000 inhab.)*	*n.d.*	*n.d.*	++	*n.d.*
	Population density	--	+	-	*n.d.*
	Population with only primary education	-	-	-	*n.d.*
	Population with tertiary education	++	++	*n.d.*	*n.d.*
	Average net income per person	++	++	+	+
	Total accommodations	*n.d.*	*n.d.*	+	*n.d.*
	Total accommodation per 1,000 inhab.	-	-	*n.d.*	*n.d.*
	Door-to-door collection model*	+++	+++	+++	+++
	Containers with controlled access *	*n.d.*	*n.d.*	+	++

*Legend: "+" or "-"; "++" or "--" and "+++" or "---" indicate, respectively, a low, medium and high impact of the independent variable on per capita collection. The positive sign, represented in different shades of green according to its intensity, indicates that the effect is produced in the same direction; that is, an increase in the independent variable implies an increase in per capita collection. The negative sign, representing shades of yellow-orange, indicates that an increase in the independent variable implies a decrease in per capita collection; "n.d." stands for "no data". This means that there are no resulting data points for this variable since it has not been estimated in this model due to lack of data or because it is not statistically significant; * correspond to dummy variables.*

Table 6. Summary of statistical results for Catalonia for kitchen waste and bio-waste based on variable

Variable	Kitchen waste	Bio-waste
Collection model - DtD	In comparison with the other collection models, the DtD model has a high impact on increasing collection, which is evident in all estimated models. The presence of containers with controlled access is also associated with an increase in kitchen waste collection, although with a medium impact and only for 2021, the year for which data is available.	Like kitchen waste results, DtD and Containers with controlled access models for bio-waste have a positive impact with medium-high intensity. It should be noted that, regarding the Containers with controlled access collection model, only 18 small municipalities had implemented it in 2021.
Population	Municipalities with a population greater than 50,000 inhabitants collect less kitchen waste per capita compared to smaller municipalities, so higher population has a negative impact on kitchen waste collection.	With a high level of impact, municipalities with less than 5,000 inhabitants obtain a higher bio-waste collection per capita. This effect is the opposite in municipalities with a population of more than 50,000 inhabitants.
Population density	Greater population density in municipalities with less than 5,000 inhabitants, although with a low level of impact, is related to a higher kitchen waste collection per capita. On the other hand, in the rest of the municipalities, population density is associated with a decrease in collection.	Like kitchen waste results, a higher population density positively affects the collection of bio-waste in municipalities with less than 5,000 inhabitants and negatively in the rest.
Tourism	Municipalities with greater tourist activity are generally associated with lower kitchen waste collection. This impact is more significant in municipalities with a population of more than 5,000 inhabitants and in the analyses carried out for the period 2010-2021, compared to the models estimated for the year 2021.	More tourist activity in the municipality is related to a slight decrease in bio-waste collection per capita. Therefore, the effect of tourism activity on the collection per capita of bio-waste is substantially less intense than that generated on the collection of kitchen waste.
Income level	Higher income levels per capita are associated with a medium positive impact on the increase in per capita collection of kitchen waste.	Like kitchen waste results, higher income levels per capita are associated with a medium positive impact and with greater bio-waste collection per capita.

Variable	Kitchen waste	Bio-waste
Other variables	Higher values of average age per capita are associated with a moderate positive impact on the increase in per capita collection of kitchen waste. Greater social inequality (measured by the Gini Index) and higher unemployment are related, with a low impact, to lower kitchen waste collection per capita.	Higher levels of population with a low level of education are related, with a low impact, to a lower bio-waste collection per capita.

The theoretical results from the statistical analysis (see Table 6 above) may be supported by the empirical know-how and experience from the management schemes and practices in Catalonia. The following takeaways were then extracted.

The DtD model, which is able to individualize the participation and monitor quality, has a high impact on increasing bio-waste collection in quality and quantity. In the field, the municipalities with this type of model represent the best management practices and results. The nascent results from containers with controlled access models must be considered with caution since they come from a limited sample of small Catalan municipalities.

In Catalonia, small municipalities have been pioneers and front-runners of more advanced models such as DtD, especially municipalities under 20,000 inhabitants. Reduced size and low density makes the implementation of DtD more feasible (for more information, see LIFE BIOBEST D2.3 **Assessment Matrix of Best Practices** and LIFE BIOBEST D3.1 **Guideline on separate collection**). Within the stated context, this is why the specific analysis considering the size of the municipalities results in higher collection per capita for municipalities below 5,000 inhabitants. This contrasts with larger municipalities (more than 50,000 inhabitants), where there is a negative relationship between population/population density and collection since, in general, they rely on open containers.

Bio-waste generation per capita is typically high in touristic areas because it includes the quantities generated by touristic establishments and visitors. Despite this, there is a negative impact of high tourism levels in material capture that can be explained by the fact that these Catalan local entities, especially coastal, have more complex bio-waste management and seasonal fluctuations (due to seasonal population changes, economic activity related to tourism, etc. For more information, see LIFE BIOBEST D2.3 **Assessment Matrix of Best Practices**). In addition, in these municipalities there is a more widespread use of open containers, which are not able to capture high rates of kitchen waste. As mentioned, this effect is more evident in larger municipalities.

As a final conclusion, social inequality and higher unemployment may be associated with lower collection per capita since the users are focused on other domestic problems. A similar effect occurs in the analysis related to populations with a low level of education but with a lower impact. In these cases, models that monitor participation such as DtD, paired with intense communication actions and continuous services, can work as a positive solution to increase the capture rates. The opposite occurs in local entities with a higher income level where higher participation in the bio-waste collection service is observed.

2.2 Main results from Italian analysis

For the case of Italy, with the aim of analyzing the determinants of the kitchen waste and bio-waste collection per capita, models have been estimated with panel and cross-sectional data for the same independent variables as for Catalonia as well as different types of waste management costs. The main unit of analysis is the municipality. Additionally, a joint analysis was carried out comparing regions according to the Nomenclature of Territorial Statistical Units (NUTS) level 1 regions: Northwest (NW), Northeast (NE), Centre, South/Insular. This comparative and complementary analysis was only carried out for the dependent variable of kitchen waste collection per capita.

In addition, the regions of South/Insular Italy have been analysed in order to compare, firstly, the impact on the collection of kitchen waste from the DtD service between 2010 and 2021 and, secondly, to analyse whether there are significant statistical differences between municipalities that, in 2010, were considered pioneers because their kitchen waste collection per capita exceeded 70 kg and municipalities with later implementation of DtD that reached this threshold in 2018.

Similar to the Catalan analysis, Table 7 presents a summary of the results of the different types of estimated models (with panel data and cross-sectional data), regarding the incidence of the different variables analysed on the kitchen waste and bio-waste collection per capita in Italy.

Table 7. Main results of the optimal models of each type of analysis carried out for Italy

	Dependent variables	**Collection of kitchen waste** (kg/inhab./year)		**Collection of bio-waste** (kg/inhab./year)	
	Type of model	Models with data panel	Models with cross-sectional data	Models with data panel	Models with cross-sectional data
	Period	2010-2021	2021	2010-2021	2021
Independent variables	Area	*n.d.*	--	*n.d.*	--
	Population	++	+++	+++	+++
	Population (municipalities w/ ≤5,000 inhab.)*	-	-	-	*n.d.*
	Population (municipalities w/ ≥50,000 inhab.)*	-	-	-	-
	Population density	*n.d.*	*n.d.*	-	--
	Foreign population	-	-	+	*n.d.*
	Average age	+	*n.d.*	--	-
	Lower secondary education	*n.d.*	*n.d.*	*n.d.*	++
	Taxable income per capita	--	*n.d.*	+++	+++
	Total accommodations per 1,000 inhab.	++	+++	*n.d.*	*n.d.*
	Total collection and treatment costs	++	+++	+	+++
	Collection costs for mixed waste	--	---	*n.d.*	*n.d.*
	Collection costs for separate waste fractions	+++	+++	+++	+
	Door-to-door collection model*	*n.d.*	+++	*n.d.*	+++
	Open waste bins*	*n.d.*	--	*n.d.*	+
	Mixed collection*	*n.d.*	*n.d.*	*n.d.*	++
	NUTS level 1 – Central Italy	*n.d.*	--	*n.d.*	---
	NUTS level 1 – Northeast Italy	*n.d.*	---	*n.d.*	+++
	NUTS level 1 – Northwest Italy	*n.d.*	---	*n.d.*	---
	NUTS level 1 – South/Insular Italy	*n.d.*	+++	*n.d.*	--

*Legend: "+" or "-"; "++" or "--" and "+++" or "---" indicate, respectively, a low, medium and high impact of the independent variable on per capita collection. The positive sign, represented in different shades of green according to its intensity, indicates that the effect is produced in the same direction; that is, an increase in the independent variable implies an increase in per capita collection. The negative sign, representing shades of yellow-orange, indicates that an increase in the independent variable implies a decrease in per capita collection; "n.d." stands for "no data. This means that there are no resulting data points for this variable since it has not been estimated in this model due to lack of data or because it is not statistically significant; * correspond to dummy variables.*

Table 8. Summary of statistical analysis results for Italy for kitchen waste and bio-waste based on variable

Variable	Kitchen waste	Bio-waste
Collection model - DtD	DtD model application, for which data is only available for 2021, reveals a high positive impact on kitchen waste collection per capita. On the other hand, the model based on open waste bins has the opposite effect, with a medium negative impact level.	DtD model application, for which data is only available for 2021, has a high positive impact on bio-waste collection per capita. Models based solely on open waste bins or in combination with the DtD system (mixed collection) present the same effect, although with a low and medium intensity impact, respectively.
Population	Increases in population are associated with greater kitchen waste collection per capita. Municipalities with less than 5,000 inhabitants and those with 50,000 or more inhabitants are associated with lower kitchen waste collection per capita, with a low level of negative impact of the variable.	Like kitchen waste results, increases in population are associated with greater bio-waste collection per capita. Municipalities with less than 5,000 inhabitants and those with 50,000 or more inhabitants tend to have a lower bio-waste collection rate per capita, with a low level of negative impact of the variable.
Population density	No significant results.	Municipalities with higher population density are associated with lower bio-waste collection per capita.
Tourism	Municipalities with higher tourism levels are associated with greater kitchen waste collection per capita.	No significant results.
Income level	Higher average income per capita in municipalities is associated with lower kitchen waste collection per capita levels.	Higher average income per capita in municipalities has a high impact on increasing bio-waste collection per capita.
Average age	Municipalities with greater average age are associated with, although at a low intensity, greater kitchen waste collection per capita.	Municipalities with greater average age are associated with lower bio-waste collection per capita.
Costs	Higher total cost of waste collection and treatment is associated with higher kitchen waste collection per capita. Specifically, a higher collection cost for separate waste fractions is associated with greater collection, while the opposite is true for collection costs for mixed waste	Higher total cost of waste collection and treatment, as well as cost of separate waste fractions cost, are associated with higher bio-waste collection per capita.

Variable	Kitchen waste	Bio-waste
NUTS	According to data available for the year 2021, a municipality that belongs to the NUTS Central, NE and NW regions is associated with lower kitchen waste collection per capita compared to the NUTS South/Insular regions.	According to data available for the year 2021, a municipality that belongs to the NUTS Central, South/Insular or NW region is associated with lower bio-waste collection per capita compared to the NUTS NE.
Early frontrunners	In the South/Insular regions of Italy, the application of DtD collection for kitchen waste has had a positive and relevant impact in both 2010 and 2021, being substantially more important in 2010 than in 2021. In the South/Insular regions of Italy, there are no statistically significant differences in the growth in the first years of the pioneering municipalities in 2010 (municipalities that exceeded 70 kg of collection per capita that year) compared to those that exceeded this amount in 2018 and 2019.	No significant results.

The theoretical results coming from the statistical analysis (see Table 8 above) may be supported by empirical know-how and experience from the management schemes and practices in Italy. By making a contextual assessment of the study results with the Italian partners of the LIFE BIOBEST project, some relevant information was extracted that can be contextualized within the framework of the practical management experience and the thousands of Italian municipalities that already have good results.

Apart from the relationships that are understood without further explanation (e.g. it is known that dedicating more capital to collecting the residual fraction causes less organic capture, since the frequency and volume collected has a bias towards the residual fraction), some peculiarities are observed. Firstly, it is proven that the DtD model reaps a greater capture of kitchen waste due to its convenience and ease in promoting a rapid and consolidated change of habits. This is especially true in cities with 5,000 to 50,000 inhabitants. The collection per capita increases with the population because it is easier to implement optimized and homogeneous systems with respect to rural areas with very low and dispersed populations.

Regarding the complementary analyses considering the NUTS and the largest proportion of kitchen waste in the regions of South/Insular Italy and islands, according to experience, it is due to the widespread habit of preparing food at home, compared to the "faster" food consumed in centralized places (work, restaurants, etc.) in the northern regions.

The context and dynamics of tourist areas (number of accommodations) do not have a negative effect. In these areas more efficient collection models were developed without problems because good practices of long experience with DtD systems for many years could be copied, added to the greater generation of kitchen waste derived from the seasonal population.

The history and results from the pioneers is noteworthy because, in line with the explanation in section 5.2.4, the pioneer frontrunners who started many years ago with the separate collection of kitchen waste in complex areas such as South/Insular Italy, managed to involve the public, possibly more than those who started separate collection later. The commitment and political will of these municipalities were crucial, compensating for the fact that they were not surrounded by other municipalities with similar management. Local entities that started later, on the contrary, had more reference points, which are important when planning national strategies in European regions that are still a long way from achieving good results over a wide area and with efficient and consolidated models.

2.3 Comparison between analyses of Catalonia and Italy

In relation to the factors that influence the kitchen waste and bio-waste collection per capita in the municipalities of both territories, when comparing the results of the econometric analyses carried out for Catalonia and Italy (with similar bio-waste management models in terms of materials requested, Ho.Re.Ca. involvement in the municipal system and green fraction collection), several noteworthy elements are revealed.

- In both territories, cross-sectional models for the year 2021 have greater explanatory power and accuracy than panel data models.
- In general, econometric analyses on kitchen waste are more accurate and better explain the factors influencing collection, compared to those of bio-waste. Models for kitchen waste are slightly more consistent and efficient, which means that the results obtained are more reliable and robust. This means that these models help to better understand the key variables that affect the collection of this waste.

Table 9. Effects on bio-waste/kitchen waste collection capture per capita of the different variables

Variable	Catalonia	Italy
Collection model - DtD	High positive impact.	High positive impact.
Population	Positive impact for medium and small municipalities, and negative impact for larger municipalities with population >50.000 inhab.	Increases in population are associated with positive impact, in general. Negative impact for larger populations.
Population density	Positive impact for small municipalities (less than 5,000 inhab.), and negative impact for larger municipalities.	Negative impact (results not differentiated by municipal population size).
Tourism	Negative impact, more intense with population >5.000	Positive impact (considering more effective collection schemes in place).
Income per capita	Positive impact.	Positive impact.

3 Data and Methodology

This section describes the main methodological steps followed in this study, specifically:

- Identification and selection of variables for analysis (see section 3.1).
- Data collection and identification of transformation needs and coding of variables.
- Methodology used for statistical analysis (see section 3.2).

These steps are detailed below, breaking down the information by study areas, specifically Catalonia (Spain) and Italy.

3.1 Identification and selection of variables

The main objective of this study is to analyse the factors that influence kitchen waste and bio-waste collection per capita at the municipal level in Catalonia and Italy during the period 2010 - 2021. These includes geographic, demographic, socioeconomic and waste management variables.

The construction of the databases for the two sample areas was carried out based on data previously collected by the LIFE BIOBEST consortium (Task 2.1) according to the interest of the study (e.g., quantities of kitchen waste collection per capita, average net annual income per household, etc.), as well as a non-exhaustive analysis of the literature on the factors that may influence municipal waste collection or generation (specific references to bio-waste are more limited in number). Table 10 summarizes the main studies analysed, which applied regression models or other types of statistical analyses. In addition, it shows the relationships (positive or negative) between independent and dependent variables.

Table 10. Studies analysed for the identification and selection of statistical analysis variables

Independent variables		Dependent variables	
		Bio-waste collection (Kg/inhab./y)	Generation of municipal solid waste (total and per capita)[a]
Demography and population	Population (inhab.)	X	↑ [4; 5; 6]
	Urban population growth		↑ [1]
	Municipal urban land (%)		↓ [3]
	Population density (inhab./km^2)	X	↓ [3; 6]; ↑ [5; 6]
	Foreigner population (%)	X	
	Rural population		↓ [5]
	Population aged 15 to 59 years		↑ [4]
	Urban density of municipality		↑ [4]
	Life expectancy		↓ [4]; ↑ [5]
	Number of households		↓↑ [6]
	Household size	↓ [2]	↓↑ [6]
Education	Population over age 10 that have completed at least university education (%)		↑ [3]
	Secondary education (% people over age 18 with a min of 8 years of study)		↑ [5]
	High education (% people over age 18 that have a min of 12 years of study)		↑ [5]
	Undergraduate education (% people over age 25 with an undergraduate degree)		↑ [5]
Economy and living conditions	Average family income	X	↑ [6]
	GDP (total)		↓ [6]; ↑ [1; 6]
	GDP per capita		↑ [6]
	Income per capita		↑ [5]
	Stratified income		↓↑ [6]
	Related Total Consumer Expenditure		↑ [6]
	Employment rate		↓ [6]
	Inequality (Gini Index)		↑ [5]
	Municipal Human Development Index		↑ [5; 6]
	Unemployment rate aged 16 to 64 (%)		↓ [3]
	Total number of employed members in a household	↑ [2]	
	Property assessment tax value (as an indication of income)	↑ [2]	
	Energy consumption		↓↑ [6]
	Water consumption		↑ [6]
Tourism	% tourism (number nights)	X	
	Hotel and catering establishments (‰ inhabitants)		↓ [3]
Waste management	Waste collection model	X	
	Waste collection costs	X	

Sources: [1](Wang & Nie, 2001); [2] (Bandara et al., 2007); [3] (Oribe-Garcia et al., 2015); [4] (Ghinea et al., 2016); [5] (Vieira & Matheus, 2018); [6] (Ribas Alzamora et al., 2022)

Legend: The sign "X" marks those variables previously considered by the consortium. The signs "↓" and "↑" indicate a negative and positive effect of the dependent variable on the independent variable, respectively.

Notes: [a] This dependent variable will not be used in the statistical analysis presented in this study, but it was analysed in this review due to the connection with the study's theme and the availability of related studies.

Based on the variables above, corresponding data was collected when available at the municipal level. In the absence of identical variables, similar variables that could cover all or part of the period of analysis (2010-2021) were selected. That said, not all variables are identical between Catalonia and Italy. In some cases, variables with the same name in both study areas presented methodological differences.

3.1.1 Catalonia

Catalonia, one of the 17 Autonomous Communities of Spain, is made up of 947 municipalities, which will be the object of analysis. The database is composed of 33 variables, including 6 identification variables (e.g., year of analysis, name of the municipality), 2 dependent variables ('Collection of kitchen waste per capita'; 'Collection of bio-waste per capita') and 28 independent variables associated with the categories of 'Territory', 'Demography and population', 'Education', 'Economy and living conditions', 'Tourism', and 'Waste management' (Table 10).

The database is composed of quantitative variables, both continuous (e.g., 'Population density', 'Average net income') and discrete (e.g., 'Population', 'Total accommodations'). In addition, qualitative variables are included in dummy format (or binary/dichotomous) (e.g., the variable 'Coastal municipality', which can assume the value 1 or 0 depending on whether the municipality is located on the coast or not, respectively).

In addition, dichotomous variables based on the size of the municipality (less than 5,000; between 5,000 and 50,000; and more than 50,000 inhabitants) have been used in the analysis of waste collection per capita. These variables help distinguish how the characteristics of each size of municipality impact collection patterns and the effectiveness of waste management policies. In fact, small municipalities tend to have better results and are those that started the implementation of advanced models with user identification earlier, mainly DtD. In this sense, the estimation of different models that analyse kitchen waste and bio-waste collection per capita has been carried out only for municipalities with a population of less than 5,000 inhabitants. This group adds up to a total of 657 municipalities out of a total of 947 in Catalonia.

Additionally, outliers have been removed from the variable 'Collection of bio-waste per capita'. Lower bound outliers correspond to bio-waste collection levels below 20 kg per inhabitant per year. Upper bound outliers, on the other hand, were identified using a formula: any value that exceeds 1.5 times the interquartile range (IQR) above the third quartile is considered an outlier. This calculation was performed for the combined Italian and Catalan data, yielding a result of over 255 kg per capita. After identifying and excluding the observations corresponding to these outliers, data for the variables referring to kitchen and garden waste collection, which are components of bio-waste, were also removed for the same period and municipality. The final database is presented as a panel dataset, which implies that it includes various variables of the municipalities observed over time. It is a short panel, since the number of municipalities is greater than the number of years and not balanced, which means that not all municipalities have data for each year of the analysis.

Table 11. Variables considered in the statistical analysis for Catalonia

Variable full name	**Variable short name** (code for statistical analysis)	Category	Description	Period of analysis	Source
Identification					
Code INE	CodeINE	Identification	Code of the municipalities according to the Spanish National Statistics.	-	Instituto Nacional de Estadística (Spanish Statistical Office) – INE. In: https://www.ine.es/daco/daco42/codmun/codmun11/11codmunmapa.htm
Code LAU	CodeLau		Code of the municipalities according to the EU's local administrative units (LAU) classification.	-	Eurostat. In: https://ec.europa.eu/eurostat/web/nuts/local-administrative-units
Municipality	Municipality		Name of the municipality.	-	-
Comarca	Comarca		Name of the comarca (an administrative unit that includes multiple municipalities and is comparable to a county or district).	-	-
Year of analysis	Year		-	-	-
Code LAU and year	Codeyear		Joint code with LAU and year.	-	-
Dependent variables					
Collection of kitchen waste per capita	KitchenWaste Cap	Waste management	Corresponds to the sum of separate collection of kitchen waste (in kg/inhab./year).	2010-2021	Statistics from the Waste Agency of Catalonia https://estadistiques.arc.cat/ARC
Collection of bio-waste per capita	Bio-wasteCap		Corresponds to the sum of collection of (kitchen waste separately collected (also includes a small flow treated in home composting*) and garden waste (in kg/inhab./year). *Home composting has a limited application, and the statistics are calculated based on a standard methodology according and the number and type of composters reported by the municipalities.	2010-2021	

Variable full name	Variable short name (code for statistical analysis)	Category	Description	Period of analysis	Source
Independent variables					
Elevation	Elevation	Territory	Average elevation of the municipality in meters.	2010-2021	Institut d'Estadística de Catalunya (Official statistics of Catalonia) – IDESCAT. In: https://www.idescat.cat/indicadors/?id=aec&n=15903&lang=es
Area	Area		Area of the municipality in km^2.	2010-2021	
Coastal municipality	Coast		Dummy variable that assumes the value "1" when the municipality is in a coastal area, and "0" otherwise.	2010-2021	Eurostat. In: https://ec.europa.eu/eurostat/web/nuts/local-administrative-units
Population	Pop	Demography and population	Number of inhabitants.	2010-2021	IDESCAT. In: https://www.idescat.cat/indicadors/?id=aec&n=15903&lang=es
Population (municipalities w/ ≤5,000 inhab.)	Pop_5000		Dummy variable that takes the value "1" when the municipality falls within this population level, and "0" otherwise.	2010-2021	Variable created from information obtained from IDESCAT. In: https://www.idescat.cat/indicadors/?id=aec&n=15903&lang=es
Population (municipalities w/ 5,001 to 50,000 inhab.)	Pop5001to50000				
Population (municipalities w/ ≥50,000 inhab.)	Pop_50000				
Population density	PopDens		Number of inhabitants per km^2.	2010-2021	Calculated based on the variables 'Population' and 'Area'.
Foreign population	ForPop		% of foreign inhabitants over the whole population.	2010-2021	Atlas Digital de las Áreas Urbanas (Urban Atlas of Spain), INE. In: https://atlasau.mitma.gob.es
Average age of the population	AverageAge		Average age of the population.	2010-2021	
Ageing index	AgeingIndex		Number of elderly population (aged 65 years and over) per 100 inhabitants.	2010-2021	
Young age dependency ratio	YouthIndex		Number of young people (aged 15-29 years) per 100 inhabitants.	2010-2021	

Variable full name	**Variable short name** (code for statistical analysis)	Category	Description	Period of analysis	Source
Population with only primary education	PrimLowStud	Education	Population aged 15 or over with only primary education (%).	2018-2020	IDESCAT. In: https://www.idescat.cat/pub/?id=eep&lang=es
Population with tertiary education	HigherEdu		Population aged 15 or over with tertiary education (%).	2018-2020	
Average net income per person	NetIncCap	Economy and living conditions	Average net income per person (in euros).	2015-2021	INE. In: https://www.ine.es/dynt3/inebase/index.htm?padre=7132
Average net income per household	NetIncHous		Average net income per household (in euros).	2015-2021	
Unemployed population	UnempPop		Proportion of unemployed population over the population aged 16 to 64.	2010-2021	Atlas Digital de las Áreas Urbanas, INE. In: https://atlasau.mitma.gob.es
Gini index for inequality	Gini		The index ranges between 0 (maximum equality) and 100 (maximum inequality).	2015-2021	INE. In: https://www.ine.es/dynt3/inebase/index.htm?padre=7132
Total accommodations	TotAccoEst	Tourism	Corresponds to the sum of hotels, camp sites and rural tourism establishments.	2010-2021	IDESCAT. In: https://www.idescat.cat/pub/?id=turall&n=6030&geo=mun
Total accommodations per 1,000 inhabitants	TotAccoEst1000		Corresponds to the sum of hotels, camp sites and rural tourism establishments per 1,000 inhabitants.	2010-2021	Calculated based on the variables 'Total accommodations' and 'Population'
Impurities	Improper	Waste management	% of impurities found in bio-waste.	2010-2021	Information obtained from Waste Agency of Catalonia
Bio-waste treated in home composting	Compost		This data is based on estimates. See comment for the parameter "Collection of bio-waste per capita".	2012-2021	Statistics from the Waste Agency of Catalonia. In: https://estadistiques.arc.cat/ARC
Garden waste	GardenWaste		Biodegradable material such as leaves and branches, usually generated from gardening the maintenance of green spaces.	2010-2021	Statistics from the Waste Agency of Catalonia.. In: https://estadistiques.arc.cat/ARC
Collection model	CollecModel		Names of the collection models: DtD; open waste bins; containers with controlled access.	2021	Own elaboration in conjunction with the Waste Agency of Catalonia

Variable full name	**Variable short name** (code for statistical analysis)	Category	Description	Period of analysis	Source
Door-to-door collection model	D2D		Dummy variable that assumes the value "1" when the municipality has a DtD system, and "0" otherwise.	2010-2021	Variable created from information obtained from Association of DtD municipalities of Catalonia Variable created from information obtained from Waste Agency of Catalonia
Door-to-door collection model coverage	CovD2D21		% of population covered by DtD collection model.	2021	
Open waste bins	OWB21		Dummy variable that assumes the value "1" when the municipality has a collection model based on open waste bins, and "0" otherwise.	2021	
Containers with controlled access	CCA21		Dummy variable that assumes the value "1" when the municipality has a collection model based on containers with controlled access, and "0" otherwise. Note: only 18 municipalities with this model.	2021	

3.1.2 Italy

In the case of Italy, the study also focused on the municipal scale. Unlike Catalonia, which maintained the same number of municipalities throughout the analysis period (2010-2021), Italy experienced a reduction in the number of municipalities, from 8,094 to 7,903 in the same period, mainly due to municipal mergers. Italian municipalities are grouped into 20 regions, which correspond to NUTS Level 2. These regions are: Abruzzo, Basilicata, Calabria, Campania, Emilia-Romagna, Friuli-Venezia Giulia, Lazio, Liguria, Lombardy, Marche, Molise, Piedmont, Puglia, Sardinia, Sicily, Tuscany, Trentino-Alto Adige, Umbria, Valle d'Aosta and Veneto. In turn, these regions are grouped into the following NUTS Level 2 areas: Northwest, Northeast, Central, South/Insular.

The database is composed of 37 variables, including 5 identification variables (e.g., year of analysis, name of the municipality), 2 dependent variables that are identical to those of the case study on Catalonia ('Collection of kitchen waste per capita'; 'Collection of bio-waste per capita') and 30 independent variables associated with the categories of 'Territory', 'Demography and population', 'Education', 'Economy and living conditions', 'Tourism', and 'Waste management' (Table 12).

As in Catalonia, the database includes quantitative (both continuous and discrete) and qualitative (dummy or dichotomous, and polytomous) variables, and is presented as a set of unbalanced panel data. In addition, outliers associated with the dependent variable 'Collection of bio-waste per capita' were also excluded following the same procedure previously described in the case of Catalonia.

Moreover, outliers for the three variables related to waste management costs were removed. This process started with the exclusion of the observations with values equal to zero, followed by the estimation and removal of lower and upper outliers using the 1.5 interquartile range (IQR) rule: any observations falling below 1.5 times than the first quartile or exceeding 1.5 times the third quartile are classified as outliers. The variable 'Collection costs for mixed waste' had lower and upper outliers of 0 and 67 Euros per capita, respectively. For the variable 'Collection costs for separate waste fractions' the lower and upper outliers were 6 and 90 Euros per capita, respectively, whereas for 'Total collection and treatment costs' it was 69 and 217 Euros per capita, respectively.

As in Catalonia, dichotomous variables based on the size of the municipality (less than 5,000, between 5,000 and 50,000, and more than 50,000 inhabitants) have been used in the analysis of per capita waste collection. In addition, for Italy, a comparative analysis of the municipalities of the different NUTS regions was carried out. This analysis was only performed for the dependent variable of kitchen waste collection per capita. The aim is to study the differences by region of the determinants of kitchen waste collection per capita during the period analysed (2010-2021) and in more depth in 2021. From region to region, there are relevant differences with respect to the efforts made in terms of waste collection, as well as of socio-economic nature. In a single region, there are similar boundary conditions regarding optimised waste management implementation (legal, obligations, incentives, treatment gate fees).

In addition, the regions of South/Insular Italy have been analysed, in order to compare, firstly, the impact on the collection of kitchen waste with the DtD service between 2010 and 2021. And, secondly, to analyse whether there are statistically significant differences in municipalities that were considered pioneers in 2010 - due to their per capita kitchen waste collection exceeding 70 kg - and those that reached this collection threshold in 2018, when the model had already become more widespread (for more details of the specific methodology applied, see section 3.2 and section 5.2.4).

Table 12. Variables considered in the statistical analysis for Italy

Variable full name	Variable short name (code for statistical analysis)	Category	Description	Period of analysis	Source
Identification					
Code LAU	CodeLau	Identification	Code of the municipalities according to the EU's local administrative units (LAU) classification.	-	Eurostat. In: https://ec.europa.eu/eurostat/web/nuts/local-administrative-units
Municipality	Municipality		Name of the municipality.	-	-
Region	Region		Name of the region, which corresponds to the EU NUTS 3 level.	-	-
Year of analysis	Year		-	-	-
Code LAU and year	Codeyear		Joint code with LAU and year.	-	-
Dependent variables					
Collection of kitchen waste per capita	KitchenWasteCap	Waste management	Corresponds to the sum of separate collection of kitchen waste (in kg/inhab./year). *This data can include a small flow treated in home composting.	2010-2021	ISPRA, National Waste Observatory. In: https://www.catasto-rifiuti.isprambiente.it/index.php?pg=nazione&advice=si
Collection of bio-waste per capita	Bio-wasteCap		Corresponds to the sum of collection of kitchen waste and garden waste (in kg/inhab./year).	2010-2021	
Independent variables					
Area	Area	Territory	Area of the municipality in km^2.	2010-2021	
Population	Pop	Demography and population	Number of inhabitants.	2010-2021	Istituto Nazionale di Statistica (Italian National Institute of Statistics) – ISTAT. In: https://www.istat.it
Population (municipalities w/ ≤5,000 inhab.)	Pop_5000		Dummy variable that takes the value "1" when the municipality falls within this population level, and "0" otherwise.	2010-2021	Variable created from information obtained from ISTAT. In: https://www.istat.it

Variable full name	Variable short name (code for statistical analysis)	Category	Description	Period of analysis	Source
Population (municipalities w/ 5,001 to 50,000 inhab.)	Pop5001to50000				
Population (municipalities w/ ≥50,000 inhab.)	Pop_50000				
Population density	PopDens		Number of inhabitants per km^2.	2010-2021	Calculated based on the variables 'Population' and 'Area'.
Foreign population	ForPop		% of foreign inhabitants over the whole population.	2010-2021	Istituto Nazionale di Statistica (Italian National Institute of Statistics) – ISTAT. In: https://www.istat.it
Average age of the population	AverageAge		Average age of the population.	2010-2021	Calculated based on data from ISTAT. In: https://www.istat.it
Ageing index	AgeingIndex		Number of elderly population (aged 65 years and over) per 100 individuals younger than 14 years old.	2010-2021	
Young age dependency ratio	YouthIndex		Ratio of the number of young people at an age when they are generally economically inactive, (i.e., under 15 years of age), compared to the number of people of working age (i.e., 15-64).	2010-2021	Istituto Nazionale di Statistica (Italian National Institute of Statistics) – ISTAT. In: https://www.istat.it
Lower secondary education	LowSecEdu	Education	Population aged 25-64 with an educational qualification no higher than lower secondary education (%). "The low education level indicator expresses the incidence of the population aged 25-64 with a low level of education (no more than a lower secondary school diploma or vocational training) or no qualifications (illiterate individuals and literate individuals without a formal educational qualification) as a percentage of the total population aged 25-64."	2018-2019	Data retrieved from the Composite Fragility Index in the ISTAT. Processing of data from the Permanent Census of Population and Housing. In: https://esploradati.istat.it

Variable full name	Variable short name (code for statistical analysis)	Category	Description	Period of analysis	Source
Taxable income	TaxInc	Economy and living conditions	"The taxable income is determined by subtracting the deductions from the aggregate income. It is accounted only for amounts greater than zero." This variable is expressed in millions of euros.	2012-2021	Ministero dell'Economia e delle Finanze (Ministry of Economy and Finance) – MEF; ISTAT. In: https://esploradati.istat.it
Taxable income per capita	TaxIncCap		Taxable income expressed in euros per capita.	2012-2021	Calculated based on the variables 'Taxable income' and 'Population'.
Unemployment rate	UnempRate		"Percentage ratio between the number of population that is looking for work aged 15 years and over and the total population of the same age group."	2011	General Population and Housing Censuses (2011). In: http://dati-censimentopopolazione.istat.it/Index.aspx
Employment rate (20-64 years)	EmpRate		"Percentage ratio between employed individuals aged 20-64 and the population aged 20-64."	2018-2019	Data retrieved from the Composite Fragility Index in the ISTAT. Processing of data from the Permanent Census of Population and Housing. In: https://esploradati.istat.it
Total accommodations	TotAccoEst	Tourism	Total number of accommodation units, including hotels and similar establishments, as well as other accommodations.	2010-2021	Istituto Nazionale di Statistica (Italian National Institute of Statistics) – ISTAT. In: https://www.istat.it
Total accommodations per 1,000 inhabitants	TotAccoEst1000		Total number of accommodation units per 1,000 inhabitants, including hotels and similar establishments, as well as other accommodations.	2010-2021	Calculated based on the variables 'Total accommodations' and 'Population'.
Total nights at accommodations	NightsAccoEst		Total number of nights at tourist accommodation establishments, hotels and similar establishments, and other accommodations	2014-2021	Istituto Nazionale di Statistica (Italian National Institute of Statistics) – ISTAT. In: https://www.istat.it
Total nights at accommodations per 1,000 inhabitants	NightsAccoEst1000		Total number of nights at tourist accommodations, hotels and similar establishments, and other accommodations per 1,000 inhabitants.	2014-2021	Calculated based on the variables 'Total nights at accommodations' and 'Population'.
Garden waste collection	GardenWasteCap		Biodegradable material such as leaves and branches, usually generated from gardening the maintenance of green spaces.	2010-2021	ISPRA, National Waste Observatory. In: https://www.catasto-rifiuti.isprambiente.it/index.php?pg=nazione&advice=si

Variable full name	Variable short name (code for statistical analysis)	Category	Description	Period of analysis	Source
Collection model	CollecModel	Waste management	Names of the collection models: DtD; containers with controlled access; community waste bins; open waste bins; mixed collection.	2021	CONAI. In: https://www.differenti-conai.com/
Door-to-door collection model	D2D21		Dummy variable that assumes the value "1" when the municipality has a DtD system, and "0" otherwise.	2021	See source of "Collection model" variable
Open waste bins	OWB21		Dummy variable that assumes the value "1" when the municipality has a collection model based on open waste bins, and "0" otherwise.	2021	See source of "Collection model" variable
Containers with controlled access	CCA21		Dummy variable that assumes the value "1" when the municipality has a collection model based on containers with controlled access, and "0" otherwise.	2021	See source of "Collection model" variable
Community waste bins	CWB21		Dummy variable that assumes the value "1" when the municipality has a collection model based on collective wheelie (shared small bin between a few buildings) waste bins, and "0" otherwise.	2021	See source of "Collection model" variable
Mixed collection	MXC21		Dummy variable that assumes the value "1" when the municipality has a collection model based on different schemes (e.g. DtD plus containers with controlled access), and "0" otherwise.	2021	See source of "Collection model" variable
Collection costs for mixed waste	MixCollecCosts		Collection costs paid by local authorities, expressed in euros per capita. Mixed waste corresponds to residual waste.	2011-2021	ISPRA, National Waste Observatory. In: https://www.catasto-rifiuti.isprambiente.it/index.php?pg=downloadcosticomune
Collection costs for separate waste fractions	SepCollecCosts		Collection costs paid by local authorities, expressed in euros per capita.	2011-2021	
Total collection and treatment costs	TotCosts		Collection and treatment costs paid by local authorities, excluding revenues from dry recyclables. Data is expressed in euros per capita.	2011-2021	

3.2 Methodology of the statistical analysis

The following statistical analyses were performed:

a) Univariant analysis (focuses on the analysis of a single variable):

- **Descriptive statistics of the data set**, including the following measures: mean, minimum, maximum, percentage change in the mean from the first to the latest year of analysis, and relative standard deviation for the year 2021. The latter indicator (expressed as a percentage) measures the deviation of the data from the averages. The descriptive statistics are provided for the variables after excluding outliers.
- **Graphical analysis** focusing on: 1) The distribution of municipalities according to region and kitchen waste collection model; and 2) The average kitchen waste collected through DtD system, open waste bins, and mixed collection by region.
- **Graphical analysis of data dispersion**, using boxplots for the variables referring to the collected kitchen waste by region and system.

b) Multivariant analysis (focuses on the analysis of multiple variables):

This represents the main part of the statistical analysis performed in this study. Various linear regression models have been developed with the aim of explaining potential factors (independent variables) affecting the municipal collection of kitchen waste and bio-waste (dependent variables). As presented in section 3.1, the independent variables are categorized under the categories of 'Territory', 'Demography and population', 'Education', 'Economy and living conditions', 'Tourism', and 'Waste management'.

This study applies linear regression models to both cross-sectional and panel data analyses. The former type of analysis focuses on data collected for various municipalities within a single year. The latter analyses data from various municipalities over several years, thus combining cross-sectional and time-series data.

In panel data analysis, the standard equation for a linear regression model can be expressed as shown in Figure 1, where:

- Y is the dependent or explained variable.
- $ß_0$ is the constant or intercept term.
- $ß_1$, $ß_{2,...,}$ $ß_n$ are the coefficients that measure the behaviour of the variable Y with respect to the variables X_1, $X_{2,...,}$ X_n. More specifically, it quantifies the expected variation in the dependent variable for a one-unit increase in the independent variable, while holding all other variables constant.
- X_1, $X_{2,...,}$ X_n are the independent or explanatory variables.
- ε is the disturbance or error term.

Figure 1. Standard equation for a multiple linear regression

$$Y_{it} = \alpha + \beta \mathcal{X}_{it} + u_{it}$$

$$Y = \beta_0 + \beta_1 \mathcal{X}_1 + \beta_2 \mathcal{X}_2 + \ldots + \beta_n \mathcal{X}_n + \mathcal{E}$$

In comparison with the panel data, the cross-sectional model formulation considers the component (t) for only a single year.

From an extensive set of models tested, the final selection is based on the following criteria:

- **Statistical significance of the parameters** - based on the individual significance test (t-Student test), ensuring significance levels of P-values lower than 0.10. This allows verifying that an independent variable has explanatory power in relation to the considered dependent variable.
- **Statistical significance of the model** - based on the global significance test (F-test of Fisher), finding significance levels of P-values lower than 0.05, indicating that the independent variables of a model can collectively be applied to explain the variation of the dependent variable.
- **Goodness of fit of the model** - measured by the coefficient of determination (R^2), which ranges between 0 and 1. The R^2 indicates the proportion of the total variation of *Y* that is explained by the estimated model. The closer to 1, the better the model fits.
- **Normal distribution of residuals** - for each value of the independent variable, the residuals have a normal distribution with a mean equal to 0. This condition can be verified by observing the histograms of the residuals, the Jarque-Bera test, and the respective P-value.
- **Absence of heteroscedasticity** - ensured by estimating the regression models with the selection of the white-cross sectional method, which corrects the standard deviations and relaxes this assumption.
- **Absence of multicollinearity** - based on the analysis of the correlation between the independent variables, the regressions of these variables, and the analysis of the variance inflation factor (VIF), to ensure that there are no high correlations between the independent variables, which could impair the precision of the model estimation.

4 Univariant analysis

This section presents a summary of the descriptive statistics along with a graphical analysis of the dataset. As mentioned before, the datasets for both Catalonia and Italy are unbalanced due to missing data for certain variables and years. This is a common occurrence when evaluating many variables.

4.1 Descriptive statistics

4.1.1 Catalonia

Key insights from the dataset on geographic, demographic, and socio-economic variables indicate that, in general, the municipalities are quite heterogeneous. This diversity is particularly evident in the relative standard deviation of population size and density, the number of accommodations, the unemployed population, and the area of the municipalities. Analysis of the variation in the mean from the first to the latest year of analysis shows an ageing trend of the population, along with improvements in income, education, employment, and equality, among others (Table 13).

Table 13. Summary statistics for geographic and socioeconomic variables - Catalonia

Category	Variable	Period of analysis	Obs. (n)	Mean	Minimum	Maximum	**Relative standard deviation** (latest year of analysis*; %)	**Variation** (% change in mean from first to latest year of analysis)
Territory	Elevation (m)	2010-2021	11,364	368.7	2.0	1,539.0	86.7%	-
	Area (km^2)		11,364	33.9	0.4	302.8	103.0%	-
Demography and population	Population (No. inhabitants)	2010-2021	11,363	8,017.2	19.0	1,664,182.0	692.7%	3.2%
	Population density (inhab./km^2)		11,363	446.2	0.7	21,724.4	352.4%	4.0%
	Foreign population (%)		11,363	9.8	0.0	52.6	67.9%	-2.2%
	Average age		11,363	43.6	33.3	60.5	7.8%	4.4%
	Ageing index		11,363	21.1	6.9	54.8	26.9%	10.5%
	Youth index		11,363	14.0	0.0	43.0	19.1%	-7.6%
Education	Population with only primary education (%)	2018-2020	2,841	15.1	0.0	43.5	35.9%	-8.7%
	Population with tertiary education (%)		2,841	29.8	10.3	63.6	25.7%	6.5%
Economy and living conditions	Average net income per person (Euros/yr)	2015-2021	6,456	13,060.1	3,281.0	30,210.0	14.3%	22.4%
	Average net income per household (Euros/yr)		6,456	33,865.2	11,388.0	86,006.0	18.7%	21.5%
	Unemployed population (%)	2010-2021	11,357	8.1	0.0	772.0	41.2%	-31.6%
	Gini index for inequality	2015-2021	6,385	29.8	20.3	46.7	11.4%	-7.2%

Category	Variable	Period of analysis	Obs. (n)	Mean	Minimum	Maximum	Relative standard deviation (latest year of analysis*; %)	Variation (% change in mean from first to latest year of analysis)
Tourism	Total accommodations (No.)	2010-2021	11,363	6.0	0.0	741.0	403.8%	14.8%
	Total accommodations per 1,000 inhabitants (No.)		11,363	8.5	0.0	170.5	193.7%	20.3%

Note: * The relative standard deviation for all variables is based on 2021, except for education-related variables, which corresponds to 2020.

Table 14 presents the summary statistics related to various waste management variables. The average annual bio-waste collection was 81.4 kg per capita, with impurities making up 9.1% of this fraction. The relative standard deviation shows significant dispersion in the data for the total collection of all fractions. As for the collection per capita, home composting and garden waste exhibited a higher level of variability in comparison to other subfractions. Analysing changes in the mean over time reveals a reduction in the quantity of impurities and in the average total collection per municipality for all the subfractions – although the absolute amounts of collection experienced a positive evolution along the period. Moreover, there was an increase in the collection per capita.

Table 14. Summary statistics for bio-waste management variables – Catalonia

Variable		Period of analysis	Obs. (n)	Mean	Minimum	Maximum	Relative standard deviation (2021; %)	Variation (% change in mean from first to latest year of analysis)
Impurities in bio-waste (%/yr)		2010-2021	8,696	9.1	0.1	63.0	73.8%	-5.2%
Total collection (in tonnes/yr)	Bio-waste treated in home composting*	2012-2021	8,368	7.3	0.0	326.4	278.1%	31.7%
	Kitchen waste	2010-2021	9,742	476.0	0.0	128,393.6	767.7%	-18.3%**
	Garden waste		9,742	109.0	0.0	13,247.3	339.5%	-20.1%**
	Bio-waste (kitchen waste+garden waste)		9,742	591.3	1.1	141,641.0	665.7%	-17.6%**
Collection per capita (in kg/yr)	Bio-waste treated in home composting*	2012-2021	8,368	8.7	0.0	232.6	255.9%	15.6%
	Kitchen waste	2010-2021	9,742	60.0	0.0	252.7	63.6%	5.5%
	Garden waste		9,742	13.9	0.0	252.5	176.1%	10.3%
	Bio-waste (kitchen waste+garden waste)		9,742	81.4	20.0	255.0	48.2%	17.5%

Notes: *Individual and community home composting (according to the Waste Agency of Catalonia standard calculation methodology and the number and type of composters reported by the municipalities); **These results are derived from the observations of 664 and 861 municipalities in 2010 and 2021, respectively.

As expected, the total amount of tonnes of bio-waste collected considering all municipalities combined increased due to the larger number of municipalities with data for the latter year (for example, bio-waste collection increased from 491,383 to 525,079 tonnes between 2010 and 2021). However, the average collection per municipality decreased. In 2021, 621 municipalities – accounting for 72.1% of those with available data – had kitchen and bio-waste collection with open waste bins. The remaining 25.8% had DtD collection, while only 2.1% utilized containers with controlled access. The mean collection value for the two subfractions was highest in municipalities using containers with controlled access, followed by those with DtD, and, lastly, open waste bins. Nevertheless, the first collection model was implemented in only a few small municipalities and showed greater dispersion of the data (Table 15).

Table 15. Summary statistics for kitchen and bio-waste collection according to the collection model – Catalonia (kg/inhab./yr; 2021)

Type of waste fraction	Collection model	Obs. (n)	Mean	Minimum	Maximum	Relative standard deviation (%)
Kitchen waste	Door-to-door	222	106.2	0.0	251.3	30.0%
	Open waste bins	621	52.9	0.0	251.3	21.9%
	Containers with controlled access	18	117.4	80.0	207.9	51.3%
	Total*	**861**	**68.0**	**0.0**	**251.3**	**48.2%**
Bio-waste	Door-to-door	222	123.4	34.2	251.3	34.9%
	Open waste bins	621	80.2	20.1	251.3	25.5%
	Containers with controlled access	18	136.7	85.6	207.9	77.5%
	Total*	**861**	**92.5**	**20.1**	**251.3**	**65.6%**

Note: * The table includes data for 861 municipalities. The remaining 86 municipalities in Catalonia did not have available data (bio-waste collection is not implemented or home composting is the implemented system).

4.1.2 Italy

The analysis of the geographic and socio-economic characteristics of Italian municipalities indicates a high heterogeneity in terms of touristic accommodation, total taxable income, population size and density, and area. Several trends can be seen over time, including an increase in the foreign population, education levels, employment rate, and taxable income, along with a slight decrease in population size and density, and ageing demographic. Furthermore, although the number of tourist accommodations has risen, there has been a decrease in overnight stays, likely due to restrictions related to COVID-19 (Table 16).

Table 16. Summary statistics for geographic and socioeconomic variables - Italy

Category	Variable	Period of analysis	Obs. (n)	Mean	Minimum	Maximum	Relative standard deviation (latest year of analysis*; %)	Variation (% change in mean from first to latest year of analysis)
Territory	Area (km^2)	2010-2021	96,124	37.7	0.02	1,286.4	132.9%	-
Demography and population	Population (No. inhabitants)	2010-2021	96,124	7,495.2	29	2,873,494	558.7%	-0.4%
	Population density (inhab./km^2)		96,124	302.0	0.7	26,465.2	214.2%	-1.8%
	Foreign population (%)		94,944	6.4	0.0	39.7	65.6%	17.0%

Category	Variable	Period of analysis	Obs. (n)	Mean	Minimum	Maximum	Relative standard deviation (latest year of analysis*; %)	Variation (% change in mean from first to latest year of analysis)
Demography and population	Average age		94,957	45.5	32.0	67.1	7.1%	6.5%
	Ageing index		94,957	214.7	21.8	5,600.0	70.1%	28.9%
	Young age dependency ratio		94,957	0.2	0.0	0.5	20.0%	-8.1%
Education	Population aged 25-64 with an educational qualification no higher than lower secondary education (%)	2018-2019	15,802	40.3	11.8	86.9	20.8%	-2.2%
Economy and living conditions	Taxable income (million Euros)	2012-2021	79,727	101.1	0.2	50,214.0	706.1%	13.7%
	Taxable income per capita (Euros)		79,436	12,330.2	1,691.9	41,264.8	24.6%	15.2%
	Unemployment rate (%)	2011	8,092	10.1	0.0	42.2	62.3%	-
	Employment rate (%)	2018-2019	15,802	64.3	33.2	92.6	15.0%	1.2%
Tourism	Total accommodations (No.)	2010-2021	96,168	23.0	0.0	21,310.0	1,134.4%	50.2%
	Total accommodations per 1,000 inhabitants (No.)		96,093	5.9	0.0	1,284.1	345.6%	19.3%
	Total nights at accommodations (No.)	2014-2021	26,519	213,069.5	0.0	61,960,166.0	426.1%	-25.9%
	Total nights at accommodations per 1,000 inhabitants (No.)		26,504	32,803.0	0.0	2,243,946.2	293.7%	-21.6%

Note: * The relative standard deviation is based on 2021 for all variables, except for education-related variables, unemployment rate, and employment rate, which correspond to 2019, 2011, and 2019, respectively.

Table 17 presents the summary statistics for the collection of kitchen and bio-waste fractions. The results show an annual bio-waste collection mean of 110.8 kg per capita. The relative standard deviation indicates a higher dispersion in the data for the garden waste (as mentioned in the previous sections, its production depends on the season and climate conditions as well as the predominance of individual houses with gardens) collection and mixed waste collection costs. By looking at the changes in the mean during the analysed period, it is possible to identify a decrease in garden waste collection in contrast to a rise in the collection of the other subfractions. Moreover, mixed waste collection costs have decreased, whereas costs for separate waste collection and for the collection and treatment combined have risen.

Table 17. Summary statistics for kitchen and bio-waste collection according to the collection model – Italy

Category	Variable	Period of analysis	Obs. (n)	Mean	Minimum	Maximum	Relative standard deviation (2021; %)	Variation (% change in mean from first to latest year of analysis)
Waste collection (kg/inhab./yr)	Kitchen waste	2010-2021	66,058	79.9	0.0	253.8	40.5%	37.4%
	Garden waste		54,987	45.2	0.0	254.1	90.7%	-18.1%
	Bio-waste (kitchen waste + garden waste)		70,097	110.8	20.0	255.0	38.3%	23.4%
Waste management costs (Euros/inhab./yr)	Mixed waste collection costs	2011-2021	73,066	21.4	0.01	67.5	70.2%	-27.4%
	Separate collection costs		71,986	36.0	6.0	90.5	41.8%	49.5%
	Total collection and treatment costs		74,256	137.8	69.0	271.5	30.6%	22.7%

In 2021, 4,287 municipalities – accounting for 62.6% of those with available data – had a DtD bio-waste collection system. The remaining 20.3% had a mixed collection model, 7.4% had no model specified, 7.1% employed open waste bins, 2.1% had containers with controlled access, and 0.5% had community waste bins. The mean collection value for the two subfractions was highest in municipalities employing DtD, followed by mixed collection, and containers with controlled access (Table 18).

Table 18. Summary statistics for kitchen and bio-waste collection according to the collection model – Italy (kg/inhab./yr.; 2021)

Type of waste fraction	Collection model	Obs. (n)	Mean	Minimum	Maximum	Relative standard deviation (%)
Kitchen waste	Door-to-door	4,252	95.4	0.9	242.2	37.3%
	Open waste bins	435	62.3	1.7	243.5	52.4%
	Containers with controlled access	145	83.1	7.4	158.0	40.9%
	Community waste bins	33	67.9	32.8	157.7	49.6%
	Mixed collection (door-to-door and waste bin)	1,324	85.0	0.5	237.0	41.4%
	NA*	486	95.2	11.8	213.3	42.8%
	Total**	**6,675**	**90.8**	**0.5**	**243.5**	**40.5%**
Bio-waste	Door-to-door	4,287	122.8	20.4	254.8	35.4%
	Open waste bins	487	108.9	20.2	253.5	50.9%

Type of waste fraction	Collection model	Obs. (n)	Mean	Minimum	Maximum	Relative standard deviation (%)
Bio-waste	Containers with controlled access	145	113.9	20.1	233.2	40.3%
	Community waste bins	33	99.4	35.7	216.7	46.0%
	Mixed collection (door-to-door and waste bin)	1,389	120.2	20.6	253.8	40.5%
	NA*	505	114.1	20.1	237.9	42.1%
	Total**	**6,846**	**120.4**	**20.1**	**254.8**	**38.3%**

Notes: * NA stands for non-available data; ** In 2021, Italy had 7,903 municipalities, but data on kitchen waste and bio-waste collection is available for 6,675 and 6,846 municipalities, respectively. This indicates that some municipalities lack information.

4.2 Comparative analysis

This section provides a comparative analysis of various waste management indicators among Catalonia, Italy, and its regions. Figure 2 shows the distribution of municipalities based on their kitchen waste collection model in 2021. Open waste bins, followed by DtD are the most prevalent systems in Catalonia, whereas DtD, and to a lesser extent mixed collection, appear as the main collection models of the Italian regions.

Figure 2. Number of municipalities according to region and kitchen waste collection model – Catalonia and Italy (2021)

Country	Region	Door-to-door	Open waste bins	Containers with controlled access	Community waste bins	Mixed collection (Door-to-door and waste bins)	NA*	Total
Spain	Catalonia (SP)	222	621	18	-	-	-	861
Italy	Abruzzo (IT)	276	1	-	-	4	4	285
	Basilicata (IT)	65	1	-	-	3	9	78
	Calabria (IT)	272	2	-	-	15	27	316
	Campania (IT)	431	2	-	4	46	56	539
	Emilia-Romagna (IT)	33	75	12	4	123	3	250
	Friuli-Venezia Giulia (IT)	104	59	-	2	41	3	209
	Lazio (IT)	259	5	-	4	19	7	294
	Liguria (IT)	90	24	20	1	52	7	194
	Lombardia (IT)	944	108	15	-	151	96	1,314
	Marche (IT)	67	18	1	1	101	25	213
	Molise (IT)	93	2	-	1	13	11	120
	Piemonte (IT)	389	135	14	8	379	65	990
	Puglia (IT)	179	1	-	-	24	5	209
	Sardegna (IT)	215	2	-	-	2	146	365
	Sicilia (IT)	320	1	-	-	8	8	337
	Toscana (IT)	87	20	18	6	94	11	236
	Trentino-Alto Adige (IT)	26	10	55	1	165	11	268
	Umbria (IT)	44	4	-	-	37	-	85
	Valle d'Aosta (IT)	-	-	-	-	-	1	1
	Veneto (IT)	393	17	10	1	112	10	543
	Total (IT)	**4,287**	**487**	**145**	**33**	**1,389**	**505**	**6,846**

Note: * NA refers to non-available data.

Figure 3 presents the mean kitchen waste collection per capita for the three most prevalent models: DtD, open waste bins, and mixed collection, the latter of which is applicable only in Italy. The results show a higher performance for the DtD system, followed by mixed collection, and open waste bins.

Figure 3. Mean kitchen waste collection obtained through DtD system, open waste bins, and mixed collection according to region – Catalonia and Italy (kg/inhab./yr; 2021)

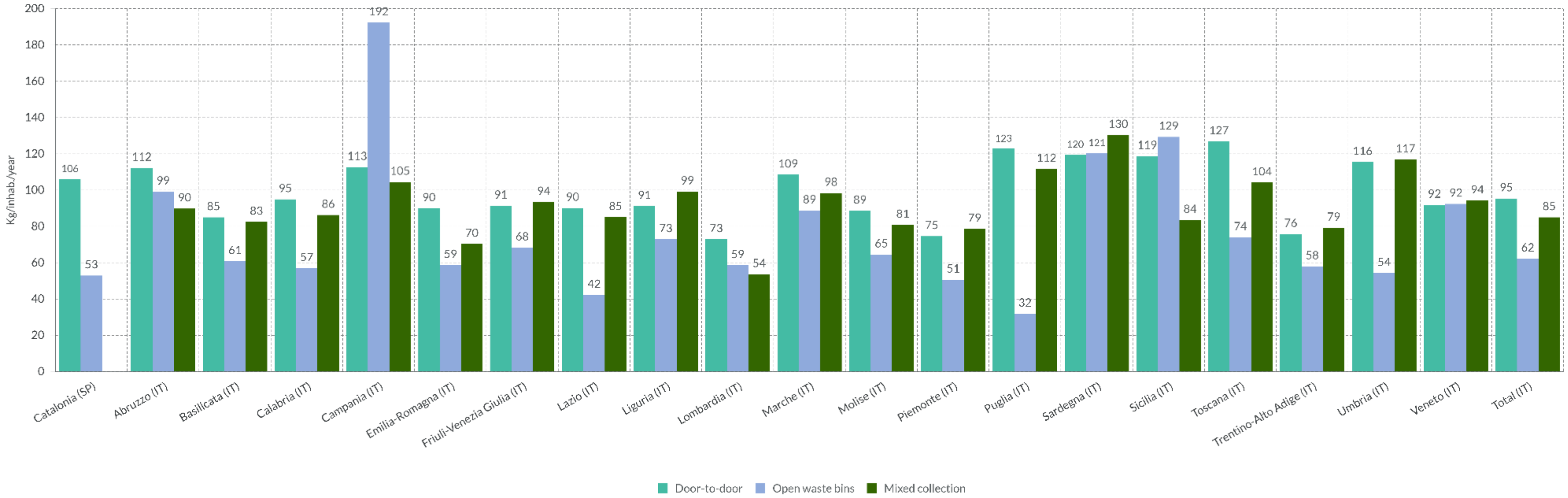
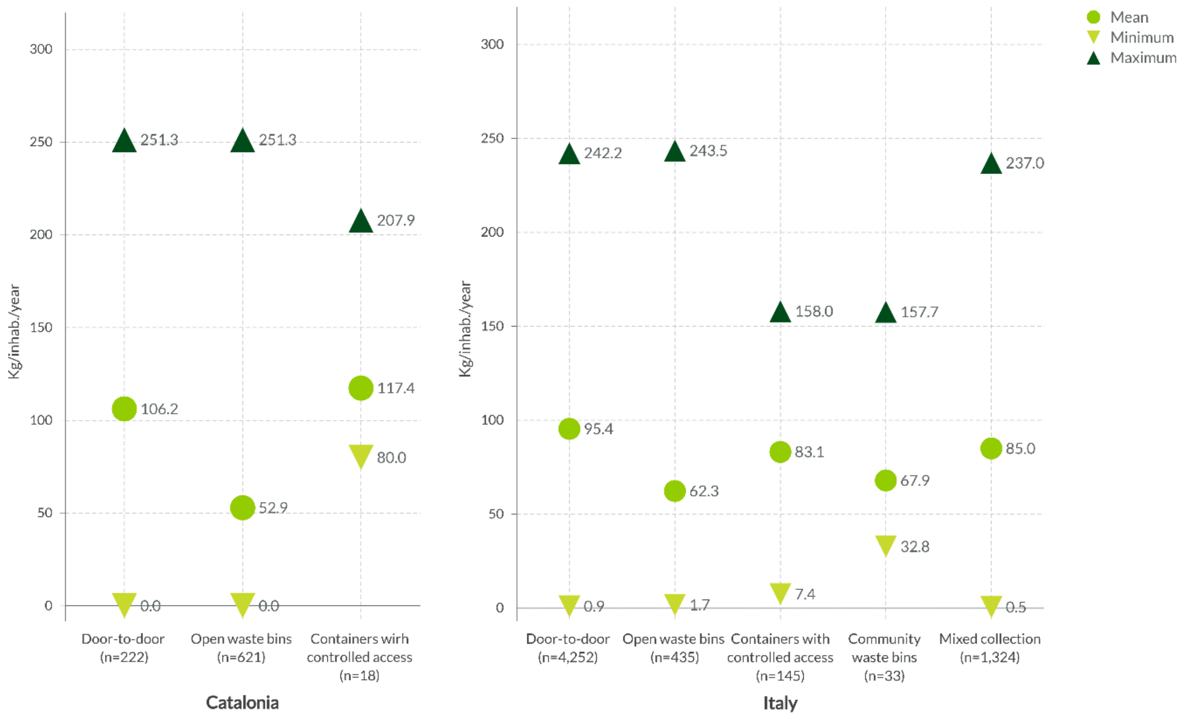


Figure 4 presents a graphical analysis of data dispersion (mean, maximum, and minimum values) for the collection of kitchen waste by region and system. The results show that DtD systems outperform other models in both study areas. In addition, the mixed collection system and containers with controlled access models also stand out in the case of Italy. Nevertheless, it is important to emphasize that containers with controlled access were only implemented in a limited number of municipalities (especially in Catalonia with 18 samples in 2021 representing quite small local entities), so the results and conclusions should be interpreted with caution.

Figure 4. Mean, maximum, and minimum kitchen waste collection for the different collection models – Catalonia and Italy (kg/inhab./yr; 2021)



5 Regression Analysis: Panel data and cross-sectional methods

With the aim of studying the factors that determine kitchen waste and bio-waste collection per capita at the municipal level in Catalonia and Italy, different types of econometric models have been built. In these, variables related to waste management and socio-economic and demographic variables have been used. The models have been estimated through an analysis of panel data for the period 2010-2021 and through cross-sectional multivariate regressions for 2021. In each type of model, the effects of waste management variables and those of a socio-economic and demographic nature have been analysed separately, which permits the study of explanatory capacity of each variable with respect to the others. For more details on the variables and methodology, see section 3.

In general, in this work, cross-sectional models show greater explanatory power and efficiency compared to panel data models. This is mainly due to the smaller amount of missing data and the absence of autocorrelation issues and temporal variability in the data. However, these estimates do not capture the impact of the temporal evolution of the explanatory variables on waste collection, which can be a significant limitation when the temporal evolution is relevant. As shown in this work, variability over time is important between municipalities and, therefore, the use of panel data is recommended.

Normally, when faced with the possibility of using panel data, these models are methodologically preferable to cross-sectional models, although they tend to present more problems related to the absence of data. Consequently, due to the lack of data in the period 2010-2021 and greater availability, especially for 2021, both types of analyses, with panel and cross-section data, are presented as complementary.

In the models estimated with panel data, the hypothesis of the absence of fixed effects is rejected, so the differential and constant effects over time of each municipality are relevant in the analysis. This implies that unique characteristics of each municipality (such as local waste policies, culture, or infrastructure) significantly affect waste collection rates and should be included in the model.

A problem observed in all the models estimated with panel data has been the presence of heteroskedasticity and first-degree autocorrelation. Therefore, the models with panel data, for which the results are presented in the following sections, both for Catalonia and for Italy, have been corrected by assuming that the perturbations are heteroskedastic (i.e., the variability of the errors is not constant) and that there is level one autocorrelation (i.e., the errors of a regression model are correlated with the errors associated with the previous period).

To address the problems of autocorrelation and heteroskedasticity identified in the analysis of panel data, a method was applied that allows robust estimates to be obtained. This approach considers the structure of errors and provides appropriate corrections, resulting in more reliable and less biased coefficients. By implementing this technique, the validity of the results obtained is improved, ensuring that the conclusions on the collection per capita are more accurate and robust in the face of the problems detected. The main causes of these problems are the significant variability of the behavior of the variables between municipalities and the omission of explanatory variables that are not observed or not available.

In general, in the models estimated for both territories, the independent variables explain a low percentage of kitchen waste and bio-waste collection per capita. This is reflected in the coefficient of determination (R2), which varies between 0 and 1. A value close to 0 indicates that the independent variables have a very limited ability to explain the variability of the dependent variable, while a value of 1 suggests that they fully explain it. The results of the study imply that there is probably an important part of the collection of this waste that is explained by variables that are not included in the statistical analysis. However, this does not affect the severity of the estimated effects of the independent variables on kitchen waste and bio-waste collection per capita.

A relevant aspect that has been observed is that, by incorporating more independent variables into the models, the number of observations included in the estimates tends to decrease due to the lack of data on these variables. Despite this, the percentage of per capita collection that they explain increases, as does the consistency of the models. This is due to the fact that the resulting subpopulations have less unexplained dispersion and greater homogeneity in terms of the behavior of the variables analysed. Causes may include greater variability in the omitted periods, the fact that explanatory variables are less determinative, or the lower reliability of data from omitted municipalities. It is important to consider this aspect when choosing the models from which conclusions will be drawn about the values of the coefficients. However, in all the cases presented, the models have been estimated with a sufficient and representative number of data, which validates both the use of panel data and the results obtained. In any case, it is a matter of choosing between maximizing the number of municipalities, variables, and years covered, or improving the accuracy of the model. In this sense, different models have been estimated and presented to show this process and try to find those that optimize this trade-off.

A common result is that, in general, the models estimated for the dependent variable kitchen waste are more efficient and consistent, and that the independent variables have a greater explanatory power than for the bio-waste variable.

In each territory, for each estimated model with cross-sectional data, a final and more exhaustive filtering of atypical data (or outliers) has been carried out, which is presented in each case in a second table. Those municipalities with data and estimated results that deviate from statistical normality and generate problems of heteroskedasticity are removed. This process has been carried out by eliminating those observations that have a value of the studentized residual (or rstudent) greater than 2, since an absolute value of this residual greater than 2 generally suggests the presence of outliers. The percentage of municipalities eliminated in this treatment was approximately 5%. However, the improvement in the efficiency and consistency of the models was remarkable, although the significance of the explanatory variables hardly changed. However, caution is needed, as this process may be removing important information for the study. Until a more in-depth analysis, this report will only be considered as an element that indicates further potential for analysis along these lines. Therefore, the interpretation and drawing of conclusions will be carried out only from the estimated models without the removal of atypical data.

Regarding the models estimated for each type of analysis, those whose explanatory variables provide more relevant information and greater explanatory power with respect to the collection per capita of each type of waste have been selected, always respecting the required levels of significance and statistical robustness standard for econometric analyses. In this sense, six models have been selected for each type of analysis, except for the NUTS analysis of Italy where only one model has been used for each region. At minimum, for each analysis, the best model for the socioeconomic variables, for the waste management variables, and for both types of variables together are presented separately. This allows results to be obtained for each type of variable separately and together.

In each analysis there is a model that combines both types of variables and has a greater explanatory power that can be considered as the most appropriate model to draw conclusions about the determinants of waste collection per capita. However, in some cases a model is presented that combines both types of variables, and which has a higher explanatory power than the rest of the models, but which has been estimated for a substantially smaller number of municipalities due to the absence of data. This happens, for example, in Table 19 of section 5.1.1.1; where model 5 has an explanatory power of 33% but is estimated for 2,550 municipalities, while model 4 has an explanatory power of 27% and is estimated for 5,821 municipalities. Both analyses are carried out on a sufficient number of data to draw rigorous conclusions, but the difference in the number of municipalities analysed must be taken into account, since in order to achieve greater explanatory power, a significant amount of information would be renounced. In any case, this fact may indicate that an analysis of smaller and more homogeneous groups of municipalities is necessary.

The structure of the results tables presented in this section is the following:

- The first column on the left presents the independent variables used in the models that, at least in some of them, have shown statistical significance. This means that there is sufficient evidence to affirm that this variable has a real effect on collection per capita.
- The rest of the columns show the results of each of the models finally estimated, identified by a number. These results correspond to the value of the regression coefficient of each variable, which indicates the impact of the independent variable on collection per capita.
- The value of the coefficient is accompanied by asterisks depending on its level of significance marked by the p-value. The minimum confidence level required in this work to consider the value of a coefficient significant is 90%. In this way, the p-value indicates the probability that the observed effect is only the product of chance, so that, if its value is less than 0.10 (or 10%), it indicates that there is sufficient evidence to conclude that the variable has a significant effect (statistically demonstrated) on collection per capita (with a certainty of 90%). The number of asterisks accompanying the value of the coefficient determines the confidence level at which it is significant, so that "***" indicates that it is 99% significant, "**" 95% and "*" 90%. The higher the confidence level, the greater the reliability of the value of the coefficient of the explanatory variable. When the coefficient is not accompanied by an asterisk, it indicates that it is not significant for a 90% confidence level.
- Finally, the last two rows show the number of observations (N) that have been used to estimate the model, as well as the coefficient of determination (R^2), which

indicates the percentage of collection per capita explained by the variables used in the model.

In this sense, it is important to note that the interpretation of the coefficients will depend on the way in which the independent variables are expressed. In the estimates made in this study, variables have been used in linear terms, in percentages, in logarithms and dichotomous variables. The coefficients of each of these variables are interpreted as follows:

- Variables in linear terms: If an independent variable is expressed linearly (as normal numbers), its coefficient shows how much the dependent variable changes for each unit that the independent variable increases. It is a direct relationship.
- Variables in percentage: When the independent variable is a percentage, the coefficient demonstrates how much the dependent variable changes when that percentage increases by one percentage point. For example, if a variable goes from 20% to 21%, the coefficient indicates how much the dependent variable will change.
- Variables in logarithms: If an independent variable is in logarithms, its coefficient shows the percentage change in the dependent variable associated with the same increase in the independent variable. Here, the effects are interpreted as relative changes rather than absolutes.
- Dichotomous variables: These are variables that can only have two values (e.g., 0 or 1). The coefficient indicates how the dependent variable changes when the dichotomous variable goes from 0 to 1.

5.1 Analysis of Catalan data

The following subsections present the results of the estimates made for Catalonia according to each type of model.

- Regarding the models with panel data, different regressions are estimated for the variables dependent on kitchen waste and bio-waste collection per capita, see section 3.1.1.
- For cross-sectional models, the same procedure is followed as for panel data models, but a more efficient estimate is added for each type of model, after a new filtering of the data, which is detailed in section 5.

Although in general the explanatory power of the models for municipalities with less than 5,000 inhabitants is lower, some differences are observed in terms of the sign and intensity of the impact of some independent variables. This indicates the differential nature of this group of municipalities, validating the need to study them separately.

5.1.1 Panel data models

Below are the results of the models estimated with panel data for Catalonia, corresponding to the period 2010-2021, and focused on kitchen waste and bio-waste collection per capita.

As discussed in section 2, in general, the explanatory power of the models is low, which indicates the lack of explanatory variables. Despite this, the variables that explain part of the waste collection per capita do so consistently and efficiently. A greater explanatory capacity of management variables can be observed compared to socio-economic and demographic variables. This occurs despite the fact that only a single dichotomous variable for the DtD service has been used in the panel data models.

5.1.1.1 Panel data analysis of the explanatory variable 'kitchen waste'

The results indicate that model 5 has the highest explanatory power (33%). However, this model has fewer observations compared to others, due to the lack of data for some variables. Model 3, which includes only the independent variable 'DtD', shows the greatest explanatory weight of this variable (23%). Regarding the socio-economic and demographic variables (model 6), they separately explain 12% of the dependent variable.

In summary, the explanatory variables that significantly determine the kitchen waste collection per capita are:

- Population (+)
- Population density (-)
- Average age (+)
- Ageing index (+)
- Income per capita (+)
- Tourism activity, measured by the number of accommodations (-)
- DtD collection (+)
- Size of the municipality: fewer than 50,000 inhabitants (+)
- Size of the municipality: 50,000 inhabitants or more (-)

Table 19. Results of the models estimated with panel data for the variable kitchen waste per capita for Catalonia at the municipal level in the period 2010-2021

Independent variables	Models					
	1	2	3	4	5	6
Intercept (constant term)	-193.2***	-240.1***	51.6***	-149.5***	-286.7***	-246.9***
Population (ln)[1]	2.4***	2.4***				3.8***
Population density	-0.002***	-0.003***		-0.001***	-0.0007*	-0.002***
Foreign population	0.2*	0.3**				
Average age					1.3***	

Independent variables	Models					
	1	2	3	4	5	6
Youth index	-0.05	0.09				
Ageing index	0.8***	0.9***				1.0***
Population with only primary education					0.3*	
Net income per capita (ln)[1]	22.9***	29.1***		20.2***	29.7***	27.8***
Unemployment rate	0.1	0.07				
Gini index	-0.2	-0.4***				
Total accommodations per 1,000 inhabitants	-0.3***	-0.4***		-0.3***	-0.5***	-0.4***
Door-to-door collection[2]	46.6***		47.8***	46.5***	47.5***	
Municipalities w/ ≤5,000 inhabitants[2]				12.4***		
Municipalities w/ 5,001 to 50,000 inhabitants[2]				15.4***		
Municipalities w/ ≥50,000 inhabitants[2]					-15.0***	-26.3***
Summary statistics						
N	5,766	5,766	9,742	5,821	2,550	5,821
R^2	0.28	0.12	0.23	0.27	0.33	0.12

Notes: P-values are indicated as follows: * p<0.10; ** p<0.05; *** p<0.01; the remaining variables are not significant; [1] These variables are expressed in natural logarithm; [2] Correspond to dummy (dichotomous) variables.

5.1.1.2 Panel data analysis for 'kitchen waste' for municipalities with a population of less than 5,000 inhabitants

To analyse the differential elements that determine collection per capita in small municipalities, Table 20 shows the results of the models estimated with panel data for municipalities in Catalonia with 5,000 inhabitants or less. Model 6 only integrates socioeconomic and demographic variables, while model 4 also includes waste management variables. Both models are recommended to draw conclusions about the determinants of kitchen waste collection. On the other hand, the importance of the variable DtD collection can once again be confirmed, which individually explains 21% of the kitchen waste collection per capita (model 3).

The explanatory variables that significantly determine the kitchen waste collection per capita in municipalities with less than 5,000 inhabitants are:

- Population (+)
- Population density (+)
- Average age (+)
- Ageing index (+)
- Income per capita (+)
- Gini index (inequality) (-)

- Tourism activity, measured by the number of accommodations (-)
- DtD collection (+)

Table 20. Results of the models estimated with panel data for the variable kitchen waste per capita for Catalonia in the period 2010-2021 and municipalities with less than 5,000 inhabitants

Independent variables	Models					
	1	2	3	4	5	6
Intercept (constant term)	-161.8***	-212.2***	50.6***	-175.7**	-150.3***	-201.3***
Population (ln)[1]	3.2***	4.8***				5.4***
Population density	0.009***	0.005*		0.007*	0.01***	
Foreign population	0.1	0.2				
Average age					1.6***	
Youth index	-0.09	0.01				
Ageing index	0.9***	1.1***				1.0***
Population with only primary education				0.7***		
Net income per capita (ln)[1]	19.0***	24.3***		24.7***	15.0***	23.0***
Unemployment rate	0.1	0.1				
Gini index	-0.3*	-0.5***		-0.5*	-0.3*	-0.4**
Total accommodations per 1,000 inhabitants	-0.3***	-0.3***		-0.3***	-0.4***	-0.3***
Door-to-door collection[2]	48.2***		49.8***	49.1***	48.3***	
Summary statistics						
N	4,362	4,362	7,366	1,916	4,362	4,362
R^2	0.26	0.09	0.21	0.30	0.26	0.09

Notes: P-values are indicated as follows: * p<0.10; ** p<0.05; *** p<0.01; the remaining variables are not significant; [1] These variables are expressed in natural logarithm; [2] Corresponds to a dummy (dichotomous) variable.

5.1.1.3 Analysis with panel data for the explained variable 'bio-waste'

Table 21 presents the results of the models estimated with panel data for Catalonia, corresponding to the period 2010-2021, and focused on the bio-waste collection per capita. Of the six models estimated, models 4 and 6 are the most efficient, since they include all types of variables and their coefficients are significant at a confidence level of 90%. These models have an explanatory power of 26% and 32%, respectively. On the other hand, model 3 indicates the importance of the DtD service management variable, as it has an explanatory power of 19% on the collection of bio-waste. The relationship between the data analysed, the variables incorporated into the model and their explanatory power was discussed in section 5.

The explanatory variables that significantly determine the bio-waste collection per capita are:

- Population density (+)
- Ageing index (+)
- Low educational level, measured by the population with only primary education (+)
- Income per capita (+)
- Tourism activity, measured by the number of accommodations (-)
- DtD collection (+)
- Size of the municipality: 5,000 or less inhabitants (+)
- Size of the municipality: 50,000 inhabitants or more (-)

Table 21. Results of the models estimated with panel data for the bio-waste per capita variable for Catalonia at the municipal level in the period 2010-2021

Independent variables	Models					
	1	2	3	4	5	6
Intercept (constant term)	-335.7***	-351.4***	75.0***	-328.5***	-276.7***	-247.7***
Population (ln)[1]	0.2	0.4				
Population density	-0.003***	-0.004***		-0.003***	-0.003***	-0.003***
Foreign population	0.2					
Youth index	-0.3					
Ageing index	-0.7***	-0.5***		-0.5***		
Population with only primary education					-0.5**	-0.5**
Population with tertiary education					0.7***	0.8***
Net income per capita (ln)[1]	44.9***	46.0***		43.9***	37.4***	33.1***
Unemployment rate	0.09	0.3**				
Gini index	0.1					
Total accommodations		0.08**		0.09***		
Total accommodations per 1,000 inhabitants	-0.08				-0.2***	-0.1**
Door-to-door collection[2]	42.9***	42.8***	44.8***	42.5***		40.8***
Municipalities w/ ≤5,000 inhabitans (compared to the baseline)[3]				7.3***	6.7**	8.0***
Municipalities w/ ≥50,000 inhabitants (compared to the baseline)[3]				-20.7***	-25.6***	-21.8***
Summary statistics						
N	5,766	5,820	9,742	5,821	2,550	2,550
R^2	0.25	0.26	0.19	0.26	0.22	0.32

Notes: P-values are indicated as follows: * p<0.10; ** p<0.05; *** p<0.01; the remaining variables are not significant; [1] These variables are expressed in natural logarithm; [2] Corresponds to a dummy (dichotomous) variable; [3] These results correspond to the relative effects of different population sizes (≤5,000 and ≥50,000 inhabitants) and are evaluated in relation to the baseline size (between 5,000 and 50,000 inhabitants)

5.1.1.4 Analysis with panel data for 'bio-waste' for municipalities with a population of less than 5,000 inhabitants

Table 22 presents the models estimated with panel data for Catalonia, focusing on municipalities with less than 5,000 inhabitants. Models 4 and 5, which consider all types of variables, have an explanatory power of 23% and 26%, respectively. Model 6, which focuses exclusively on socioeconomic and demographic variables, has an explanatory power of 15% of the collection per capita. These are the recommended models to draw conclusions about the determinants of bio-waste collection. On the other hand, it is important to note that, individually, the 'DtD' variable explains 18% of the collection per capita (model 3).

The explanatory variables that significantly determine the bio-waste collection per capita in municipalities with less than 5,000 inhabitants are:

- Population density (+)
- Ageing index (+)
- Low educational level, measured by the pop. with only primary education (-)
- High educational level, measured by the population with tertiary education (+)
- Income per capita (+)
- Tourism activity, measured by the number of accommodations (+)
- DtD collection (+)

Table 22. Results of the models estimated with panel data for the bio-waste per capita variable for Catalonia in the period 2010-2021 and municipalities with less than 5,000 inhabitants

Independent variables	Models					
	1	2	3	4	5	6
Intercept (constant term)	-327.6***	-357.1***	74.0***	-338.3***	-253.0***	-238.7***
Population (ln)[1]	-1.0	1.1				
Population density	0.008*	0.005		0.007*	0.008*	
Ageing index	-0.5***	-0.3		-0.4***		
Population with only primary education					-0.5*	-0.5*
Population with tertiary education					0.7***	0.6**
Net income per capita (ln)[1]	44.2***	46.4***		44.5***	33.7***	33.7***
Unemployment rate	0.3*	0.2		0.3*		
Total accommodations per 1,000 inhabitants	-0.03	-0.07			-0.2*	-0.2***
Door-to-door collection[2]	43.0***		44.9***	42.9***	40.2***	
Summary statistics						
N	4,416	4,416	7,366	4,416	1,942	1,942
R^2	0.23	0.13	0.18	0.23	0.26	0.15

Notes: P-values are indicated as follows: * p<0.10; ** p<0.05; *** p<0.01; the remaining variables are not significant; [1] These variables are expressed in natural logarithm; [2] Corresponds to a dummy (dichotomous) variable.

5.1.2 Cross-sectional models

This section presents the results of the estimated cross-sectional models for Catalonia, considering the year 2021, focusing on the variables dependent on the per capita collection of kitchen waste and bio-waste. The estimates have been made at the municipal level, using different models for all municipalities and for those with populations less than or equal to 5,000 inhabitants.

5.1.2.1 Cross-sectional analysis for the explained variable 'kitchen waste'

Table 23 shows the estimated cross-sectional models for kitchen waste collection per capita. In model 6, the independent variables explain 38% of the dependent variable, while in models 1 and 2, the waste management variables separately explain 32%. On the other hand, in model 5, socio-economic and demographic variables explain 10% of the dependent variable. In summary, the variables that explain the collection per capita with a significance within 90% confidence are:

- Area of the municipality (-)
- Population (+)
- Average age (+)
- Unemployed population (-)
- Tourism activity, measured by the number of accommodations (-)
- DtD collection (+)
- Collection model based on containers with controlled access (+)
- Collection model based on open waste bins (-)
- Size of the municipality: 5,000 or less inhabitants (+)
- Size of the municipality: between 5,000 and 50,000 inhabitants (+)

Table 23. Results of the estimated cross-sectional models for the variable kitchen waste per capita for Catalonia at the municipal level for the year 2021

Independent variables	Models					
	1	2	3	4	5	6
Intercept (constant term)	52.9***	106.2***	-199.5	-231.7	-156.5***	-125.0***
Area			-0.1***	-0.1***	-0.1***	-0.1***
Coastal municipality[1]			-4.4	0.07		
Population (ln)[2]			8.2***	6.4***	8.9***	7.6***
Population density			-0.004***	-0.003***	-0.004***	-0.003***
Average age			2.9***	2.12***	3.2***	2.5***
Population with tertiary education			-0.3	-0.3		
Net income per capita (ln)[2]			9.2	13.9		

Independent variables	Models					
	1	2	3	4	5	6
Unemployment rate			-1.7**	-1.5**	-1.7***	-1.6***
Gini index			-0.3	0.4		
Total accommodations per 1,000 inhabitants			-0.4***	-0.3**	-0.3***	-0.2**
Door-to-door collection[1]	53.4***	*omitted*[3]		50.0***		50.2***
Containers with controlled access[1]	64.5***	11.2		62.9***		66.5***
Open waste bins[1]		-53.4***				
Municipalities w/ ≤5,000 inhabitants[1]			37.9***	29.6***	41.2***	31.7***
Municipalities w/ 5,001 to 50,000 inhabitants[1]			26.0***	23.4***	28.4***	25.1***
Summary statistics						
N	861	861	818	818	860	860
R^2	0.32	0.32	0.10	0.37	0.10	0.38

Notes: P-values are indicated as follows: * p<0.10; ** p<0.05; *** p<0.01; the remaining variables are not significant; [1] Correspond to dummy (dichotomous) variables; [2] These variables are expressed in natural logarithm; [3] This variable was omitted due to problems of collinearity.

Table 24 presents the results after the debugging explained in section 5. It can be seen how both the significance of the coefficients and the explanatory power of each model improve substantially. In this sense, in model 6, the set of independent variables explains 52% of the per capita collection of kitchen waste for 822 municipalities. Separately, the management variables (models 1 and 2) and the socio-economic and demographic area (model 5) explain 42% and 17% of the dependent variable, respectively.

Table 24. Results of the estimated cross-sectional models for the variable kitchen waste per capita for Catalonia at the municipal level for the year 2021 (after eliminating outliers)

Independent variables	Models					
	1	2	3	4	5	6
Intercept (constant term)	49.1***	105.4***	-115.6	-183.1*	-219.3***	-175.2***
Area			-0.1***	-0.1***	-0.1***	-0.1***
Coastal municipality[1]			-4.5	-0.3		
Population (ln)[2]			11.6***	9.3***	11.2***	9.4***
Population density			-0.004***	-0.003***	-0.004***	-0.003***
Average age			3.9***	2.9***	4.1***	3.2***
Population with tertiary education			-0.2	-0.3		
Net income per capita (ln)[2]			-7.4	2.4		
Unemployment rate			-2.4***	-1.9***	-1.9***	-1.6***
Gini index			-0.5	0.3		
Total accommodations per 1,000 inhabitants			-0.5***	-0.4***	-0.5***	-0.3***
Door-to-door collection[1]	56.3***	*omitted*[3]		51.6***		52.1***

Independent variables	Models					
	1	2	3	4	5	6
Containers with controlled access[1]	59.2***	3.0		51.4***		60.7***
Open waste bins[1]		-56.3***				
Municipalities w/ ≤5,000 inhabitants[1]			46.7***	37.5***	47.4***	37.0***
Municipalities w/ 5,001 to 50,000 inhabitants[1]			30.1***	26.6***	31.4***	27.2***
Summary statistics						
N	822	822	781	781	822	822
R^2	0.42	0.42	0.18	0.52	0.17	0.52

Notes: P-values are indicated as follows: * p<0.10; ** p<0.05; *** p<0.01; the remaining variables are not significant; [1] Correspond to dummy (dichotomous) variables; [2] These variables are expressed in natural logarithm; [3] This variable was omitted due to problems of collinearity.

5.1.2.2 Cross-sectional analysis for 'kitchen waste' for municipalities with a population of less than 5,000 inhabitants

At this point, the results equivalent to section 5.1.2.1 are presented, but only considering municipalities with a population of less than 5,000 inhabitants. In model 6, the independent variables explain 39% of the per capita collection of kitchen waste for 656 municipalities, while the separate waste management variables explain 33% (models 1 and 2). On the other hand, in model 5, socio-economic and demographic variables explain 12% of the dependent variable.

According to the results shown in Table 25, the explanatory variables that significantly determine the kitchen waste collection per capita are:

- Area of the municipality (-)
- Coastal municipality (-)
- Population (+)
- Average age (+)
- Unemployed population (-)
- Tourism activity, measured by the number of accommodations (-)
- DtD collection (+)
- Collection model based on containers with controlled access (+)
- Collection model based on open waste bins (-)

Table 25. Results of the estimated cross-sectional models for the variable kitchen waste per capita for Catalonia at the municipal level for the year 2021 and municipalities with less than 5,000 inhabitants

Independent variables	Models					
	1	2	3	4	5	6
Intercept (constant term)	51.8***	107.2***	-52.5	-110.1	-142.1***	-110.5***
Area			-0.2***	-0.1***	-0.2***	-0.1***
Coastal municipality[1]			-6.6	-9.2*	-22.5***	
Population (ln)[2]			8.6***	8.4***	11.0***	8.8***
Average age			2.4***	2.5***	3.4***	2.7***
Population with only primary education			0.1			
Net income per capita (ln)[2]			1.7	1.0		
Unemployment rate			-0.9	-1.0		-1.4**
Gini index			0.02	-0.07		
Total accommodations per 1,000 inhabitants			-0.2	-0.2	-0.3**	-0.2*
Door-to-door collection[1]	55.4***		-72.8	50.9***		51.5***
Door-to-door coverage			0.6			
Containers with controlled access[1]	65.6***	10.2		63.0***		67.5***
Open waste bins[1]		-55.4***	-63.5***			
Summary statistics						
N	657	657	617	630	657	656
R^2	0.33	0.33	0.38	0.38	0.12	0.39

Notes: P-values are indicated as follows: * p<0.10; ** p<0.05; *** p<0.01; the remaining variables are not significant; [1] Correspond to dummy (dichotomous) variables; [2] These variables are expressed in natural logarithm.

Table 26 presents the results after the filtration explained in section 5. It can be seen how the explanatory power of the different models estimated increases significantly, so that, in model 6, the set of independent variables explains 53% of the kitchen waste collection per capita for municipalities with less than 5,000 inhabitants.

Table 26. Results of the cross-sectional models estimated for the variable kitchen waste per capita for Catalonia at the municipal level for the year 2021 and municipalities with less than 5,000 inhabitants (after eliminating outliers)

Independent variables	Models					
	1	2	3	4	5	6
Intercept (constant term)	48.2***	105.8***	-7.3	-42.2	-200.4***	-154.9***
Area			-0.2***	-0.2***	-0.2***	-0.2***
Coastal municipality[1]			-5.1	-7.6*	-20.2***	
Population (ln)[2]			10.6***	11.0***	13.4***	10.7***
Average age			2.9***	3.2***	4.2***	3.4***
Population with only primary education			0.3			

Independent variables	Models					
	1	2	3	4	5	6
Net income per capita (ln)[2]			-8.2	-11.3		
Unemployment rate			-1.4**	-1.4**		-1.5***
Gini index			-0.03	-0.02		
Total accommodations per 1,000 inhabitants			-0.3***	-0.3***	-0.3***	-0.3***
Door-to-door collection[1]	57.6***		-11.2	51.3***		52.1***
Door-to-door coverage			0.1			
Containers with controlled access[1]	60.2***	2.5		52.6***		60.8***
Open waste bins[1]		-57.6***	-51.2***			
Summary statistics						
N	626	626	588	601	626	626
R^2	0.42	0.42	0.53	0.53	0.20	0.53

Notes: P-values are indicated as follows: * p<0.10; ** p<0.05; *** p<0.01; the remaining variables are not significant; [1] Correspond to dummy (dichotomous) variables; [2] These variables are expressed in natural logarithm.

5.1.2.3 Cross-sectional analysis for the explanatory variable 'bio-waste'

Table 27 shows the results of the estimated cross-sectional models for bio-waste collection per capita. In model 6, the independent variables explain 27% of the collection per capita for 846 municipalities analysed, while the waste management variables separately explain 20% in models 1 and 2. On the other hand, in model 5, socio-economic and demographic variables explain 7% of the dependent variable.

In summary, the variables that explain the dependent variable with a significance within 90% confidence are:

- Area of the municipality (-)
- Population density (+)
- Income per capita (+)
- Tourism activity, measured by the number of accommodations (+)
- DtD collection (+)
- Collection model based on containers with controlled access (+)
- Collection model based on open waste bins (-)
- Size of the municipality: 5,000 or less inhabitants (+)
- Size of the municipality: between 5,000 and 50,000 inhabitants (+)

Table 27. Results of the estimated cross-sectional models for the bio-waste per capita variable for Catalonia at the municipal level for the year 2021

Independent variables	Models					
	1	2	3	4	5	6
Intercept (constant term)	80.2***	123.4***	-200.6	-228.6	-392.7***	-326.1***
Area			-0.1**	-0.09**	-0.1***	-0.1***
Coastal municipality[1]			19.4***	23.3***		
Population (ln)[2]			2.0	0.4		
Population density			-0.005***	-0.005***	-0.005***	-0.004***
Average age			0.7	0.02		
Population with only primary education						-0.7**
Population with tertiary education			0.6*	0.6*		
Net income per capita (ln)[2]			23.6	27.7	49.1***	42.2***
Unemployment rate			-0.9	-0.7		
Gini index			-0.6	0.1		
Total accommodations					0.1***	0.08*
Total accommodations per 1,000 inhabitants			-0.2	-0.09		
Door-to-door collection[1]	43.3***	*omitted*[3]		44.1***		42.5***
Containers with controlled access[1]	56.5***	13.3*		56.2***		51.4***
Open waste bins[1]		-43.3***				
Municipalities w/ ≤5,000 inhabitants[1]			31.5***	24.3***	21.4***	17.0***
Municipalities w/ 5,001 to 50,000 inhabitants[1]			29.1***	26.8***	27.2***	25.5***
Summary statistics						
N	861	861	818	818	860	843
R^2	0.20	0.20	0.10	0.31	0.07	0.27

Notes: P-values are indicated as follows: * p<0.10; ** p<0.05; *** p<0.01; the remaining variables are not significant; [1] Correspond to dummy (dichotomous) variables; [2] These variables are expressed in natural logarithm; [3] This variable was omitted due to problems of collinearity.

Table 28 presents the results after the debugging explained in section 5. In model 6, the set of independent variables explains 39% of the per capita collection of kitchen waste for 805 municipalities. Separately, management variables, in models 1 and 2, and socio-economic and demographic variables, in model 5, explain 32% and 8%, respectively.

Table 28. Results of the estimated cross-sectional models for the bio-waste per capita variable for Catalonia at the municipal level for the year 2021 (after eliminating outliers)

Independent variables	Models					
	1	2	3	4	5	6
Intercept (constant term)	74.5***	121.5***	-276.3*	-352.3***	-364.6***	-455.5***
Area			-0.09**	-0.07*	-0.1***	-0.1***
Coastal municipality[1]			13.2***	16.5***		
Population (ln)[2]			2.6	1.0		
Population density			-0.005***	-0.004***	-0.004***	-0.003***
Average age			0.5	-0.3		
Population with only primary education						-0.03
Population with tertiary education			0.3	0.2		
Net income per capita (ln)[2]			32.6**	42.3***	45.8***	54.1***
Unemployment rate			-0.9	-0.7		
Gini index			-0.6	0.2		
Total accommodations					0.1	0.2
Total accommodations per 1,000 inhabitants			-0.2*	-0.09		
Door-to-door collection[1]	47.0***	*omitted*[3]		48.0***		47.5***
Containers with controlled access[1]	62.5***	15.5**		61.9***		57.4***
Open waste bins[1]		-47.0***				
Municipalities w/ ≤5,000 inhabitants[1]			32.9***	25.1***	20.6***	16.4***
Municipalities w/ 5,001 to 50,000 inhabitants[1]			28.6***	25.4***	24.5***	23.2***
Summary statistics						
N	805	805	781	781	805	805
R^2	0.32	0.32	0.10	0.41	0.08	0.39

Notes: P-values are indicated as follows: * p<0.10; ** p<0.05; *** p<0.01; the remaining variables are not significant; [1] Correspond to dummy (dichotomous) variables; [2] These variables are expressed in natural logarithm; [3] This variable was omitted due to problems of collinearity.

5.1.2.4 Cross-sectional analysis for 'bio-waste' for municipalities with a population of less than 5,000 inhabitants

At this point, the results equivalent to section 5.1.2.3 are presented, focusing the estimates on municipalities with a population of less than 5,000 inhabitants. In model 6, the independent variables explain 23% of the bio-waste collection per capita for 656 municipalities, while the waste management variables separately explain 19% (models 1 and 2). On the other hand, socio-economic and demographic variables explain only 3% of the dependent variable (model 5).

According to the results shown in Table 29, the explanatory variables that significantly determine the per capita collection of kitchen waste are:

- Area of the municipality (+)
- Income per capita (+)
- DtD collection (+)
- Collection model based on containers with controlled access (+)
- Collection model based on open waste bins (-)

Table 29. Results of the estimated cross-sectional models for the bio-waste per capita variable for Catalonia at the municipal level for the year 2021 and municipalities with less than 5,000 inhabitants

Independent variables	Models					
	1	2	3	4	5	6
Intercept (constant term)	81.0***	121.2***	-211.6	-369.4***	-283.2**	-408.7***
Area			-0.09*	-0.08*	-0.1***	-0.1***
Coastal municipality[1]			23.7***	21.1***		
Population (ln)[2]			1.5	-0.3		
Average age			0.2	-0.3		
Population with only primary education			-0.6*			
Net income per capita (ln)[2]			35.7**	49.4***	39.9***	51.6***
Unemployment rate			-0.4	-0.6		
Gini index			-0.02	-0.06		
Total accommodations per 1,000 inhabitants			-0.01	-0.04		
Door-to-door collection[1]	40.2***	*omitted*[3]	-65.8*	43.6***		42.2***
Door-to-door coverage			0.6			
Containers with controlled access[1]	55.7***	15.5**		55.5***		51.7***
Open waste bins[1]		-40.2***	-54.8***			
Summary statistics						
N	657	657	617	630	656	656
R^2	0.19	0.19	0.26	0.25	0.03	0.23

Notes: P-values are indicated as follows: * p<0.10; ** p<0.05; *** p<0.01; the remaining variables are not significant; [1] Correspond to dummy (dichotomous) variables; [2] These variables are expressed in natural logarithm; [3] This variable was omitted due to problems of collinearity.

Table 30 presents the results after the filtration explained in section 5. In model 6, the set of independent variables explains 36% of the per capita collection of bio-waste for 623 municipalities. Separately, management variables (models 1 and 2) and socio-economic and demographic variables (model 5) account for 33% and 3%, respectively.

Table 30. Results of the estimated cross-sectional models for the bio-waste per capita variable for Catalonia at the municipal level for the year 2021 and municipalities with less than 5,000 inhabitants (after eliminating outliers)

Independent variables	Models					
	1	2	3	4	5	6
Intercept (constant term)	74.1***	119.9***	-250.2**	-323.8***	-203.5*	60.5***
Area			-0.08*	-0.08*	-0.1***	-0.1***
Coastal municipality[1]			14.7**	11.2**		9.8*
Population (ln)[2]			1.5	1.8		3.5***
Average age			-0.5	-0.2		
Population with only primary education			0.1			
Net income per capita (ln)[2]			42.2***	42.0***	31.0***	
Unemployment rate			-0.4	-0.6		-1.3**
Gini index			-0.1	-0.1		
Total accommodations per 1,000 inhabitants			-0.02	-0.01		0.2**
Door-to-door collection[1]	45.8***	*omitted*[3]	-45.7	47.4***		46.6***
Door-to-door coverage			0.3			
Containers with controlled access[1]	62.6***	16.8**		62.5***		65.6***
Open waste bins[1]		-45.8***	-61.2***			
Summary statistics						
N	624	624	589	599	624	623
R^2	0.33	0.33	0.37	0.37	0.03	0.36

Notes: P-values are indicated as follows: * p<0.10; ** p<0.05; *** p<0.01; the remaining variables are not significant; [1] Correspond to dummy (dichotomous) variables; [2] These variables are expressed in natural logarithm; [3] This variable was omitted due to problems of collinearity.

5.1.3 Results of the standardised coefficients for the main models estimated for Catalonia

Table 31 and Table 32 show the estimates of the main models of each type (panel and cross-sectional data) with the standardized coefficients. This makes it possible to compare the value of the coefficients of the different independent variables with each other, as well as to evaluate the impact, in each model, of each variable on collection per capita. It should be noted that the coefficients of the models with panel and cross-sectional data are not directly comparable due to differences in model structure, data, and standardization methodologies. Table 31 and Table 32 present the results of the optimal models for the panel and cross-sectional data formats, respectively. Each table indicates the model that has been used to estimate the standardized coefficients of each type of model, which coincides with the model with the greatest explanatory power in each type of analysis.

Table 31. Estimated standardised coefficients of the main models with panel data for Catalonia

Independent variables (standardized)	Models			
	Kitchen waste (No 5)	**Kitchen waste** (municipalities w/ ≤5,000 inhab.) (No 5)	**Bio-waste** (No 6)	**Bio-waste** (municipalities w/ ≤5,000 inhab.) (No 5)
Population density	-1.1	3.0	-4.7	1.8
Average age	5.0	5.9	*N.A.*	*N.A.*
Population with only primary education	1.8	*N.A.*	-2.9	-2.6
Population with tertiary education	*N.A.*	*N.A.*	6.0	5.2
Net income per capita (ln)[1]	4.7	2.4	5.3	5.3
Total accommodations per 1,000 inhabitants	-7.6	-6.8	-2.2	-2.1
Door-to-door collection[2]	17.7	18.3	15.2	15.2
Municipalities w/ ≤5,000 inhabitants[2]	*N.A.*	*N.A.*	8.0	*N.A.*
Municipalities w/ ≥50,000 inhabitants[2]	-2.3	*N.A.*	-21.8	*N.A.*

Notes: [1] This variable is expressed in natural logarithm; [2] Correspond to dummy (dichotomous) variables; N.A. stands for non-applicable data. There are no estimates for these variables due to insufficient data or lack of statistical significance.

Table 32. Estimated standardised coefficients of the main models with cross-sectional data for Catalonia

Independent variables (standardized)	Models			
	Kitchen waste (No 6)	**Kitchen waste** (municipalities w/ ≤5,000 inhab.) (No 6)	**Bio-waste** (No 6)	**Bio-waste** (municipalities w/ ≤5,000 inhab.) (No 6)
Area	-0.1	*N.A.*	-0.1	-0.1
Population (ln)[1]	0.3	0.2	*N.A.*	*N.A.*
Population density	-0.1	*N.A.*	-0.1	*N.A.*
Average age	0.2	0.2	*N.A.*	*N.A.*
Population with only primary education	n.d.	n.d.	-0.08	*N.A.*
Unemployment rate	-0.09	-0.08	*N.A.*	*N.A.*
Net income per capita (ln)[1]	*N.A.*	*N.A.*	0.1	0.2
Total accommodations	*N.A.*	*N.A.*	0.05	*N.A.*
Total accommodations per 1,000 inhabitants	-0.09	-0.08	*N.A.*	*N.A.*
Door-to-door collection[2]	0.5	0.5	0.4	0.4
Containers with controlled access[2]	0.2	0.2	0.2	0.2
Municipalities w/ ≤5,000 inhabitants[2]	0.3	*N.A.*	0.2	*N.A.*
Municipalities w/ 5,001 to 50,000 inhabitants[2]	0.2	*N.A.*	0.2	*N.A.*

Notes: [1] This variable is expressed in natural logarithm; [2] Correspond to dummy (dichotomous) variables; N.A. stands for non-available data. There are no estimates for these variables due to insufficient data or lack of statistical significance.

5.2 Analysis of Italian data

The following subsections present the results of the estimates made for each type of model.

- Regarding the models with panel data, different regressions are estimated for the variables dependent on kitchen waste and bio-waste collection per capita for all municipalities in Italy. For this type of model, the only waste management variable considered in the analyses has been the total costs of waste treatment and collection.
- For cross-sectional models, the procedure is the same as for panel data models, but adding a more efficient estimate for each type of model after a filtration of the data explained in section 5.
- For a regional comparative analysis of the determinants of kitchen waste collection per capita, models have been estimated with panel and cross-sectional data for each level 1 of the NUTS territorial unit, which classifies the regions as follows: i) Northwest (NW): Piedmont, Valle d'Aosta, Liguria and Lombardy; (ii) Northeast (NE): Trentino-Alto Adige, Veneto, Friuli-Venezia Giulia and Emilia-Romagna; (iii) Central: Tuscany, Umbria, Marche and Lazio; and (iv) South/Insular (S_Ins): Abruzzo, Molise, Campania, Puglia, Basilicata, Calabria, Sicily and Sardinia.

Regarding the analyses carried out for the regions of South/Insular Italy, a linear regression of difference-in-differences (DiD) model has been used to analyse the comparative impact between the years 2010 and 2021 of the DtD service on the collection of kitchen waste. On the other hand, the analysis of the growth of municipalities that in 2010 exceeded 70 kg of kitchen waste collection per capita, compared to those that did so in 2018, has been carried out through the T-test of comparison of means and a cross-sectional regression. For more details of the variables and data used, see section 3.

5.2.1 Panel data models

In general, the explanatory power of the models is low, indicating the lack of explanatory variables. A greater weight can be observed in management variables, even considering that in the case of panel data models, only variables related to waste management costs have been used. Socio-economic and demographic variables have less explanatory power.

Regarding management cost variables, it is important to note that, in general, they can present a situation of reverse causality, i.e. they can also be explained (or determined) by the model-dependent variable, the collection per capita. This can impair the consistency and efficiency of the coefficients of these variables, including other independent variables included in the model. However, the results suggest that the impact of cost variables on other variables is not relevant since there are no major differences between the models estimated with and without these variables. In any case, these results should be analysed with caution and even limited to considering them as a correlation with the waste collection variable. To deepen the analysis of the impact of this variable, econometric models that include instrumental variables may be considered.

5.2.1.1 Analysis of the explanatory variable 'kitchen waste'

Table 33 shows the different models estimated with panel data for Italy, considering the dependent variable 'kitchen waste' and the period 2010-2021. Note that the models vary significantly in terms of the number of observations considered and the explanatory power, depending on whether they consider different configurations of independent variables. In this sense, models 4 and 5, which only incorporate socio-economic and demographic variables, have an explanatory power of 16% and 9% for a total of 20,679 and 55,609 data analysed, respectively. In model 2, the explanatory variables of waste collection and treatment costs explain 32% of kitchen waste collection per capita. However, this does not necessarily mean that there is causality, but that the goodness of fit (R2) indicates a positive correlation between both variables. Together, the independent variables explain 36% of the dependent variable (model 3) for a total of 26,466 observations.

The explanatory variables that significantly determine the kitchen waste collection per capita are:

- Population (+)
- Population density (+)
- Foreign population (-)
- Average age (+)
- Income per capita (+)
- Tourism activity, measured by the number of accommodation & nights stays (+)
- Total collection and treatment costs (+)
- Collection costs for mixed waste (-)
- Collection costs for separate waste fractions (+)
- Size of the municipality: 5,000 or less inhabitants (-)
- Size of the municipality: 50,000 or more inhabitants (-)

Table 33. Results of the models estimated with panel data for the variable kitchen waste per capita for Italy at the municipal level in the period 2010-2021

Independent variables	Models					
	1	2	3	4	5	6
Intercept (constant term)	263.9***	-43.5***	131.4***	94.9***	73.4***	151.9***
Population (ln)[1]	5.2***		4.6***	4.8***	6.0***	3.0***
Population density	-0.001			0.001***	0.002***	
Foreign population	-0.3**		-0.8***	-0.7***	-0.6***	-0.5***
Average age	-0.09		0.3***	2.3***	1.8***	0.9***

Independent variables	Models					
	1	2	3	4	5	6
Lower secondary education	-0.4***					
Taxable income per capita (ln)[1]	-31.2***		-21.6***	-15.5***	-12.7***	-23.9***
Employment rate	-0.02					
Total accommodations per 1,000 inhabitants	0.5***		0.2***	0.08***	0.2***	
Total nights at accommodations per 1,000 inhabitants				0.0001***		0.0002***
Total collection and treatment costs (ln)[1]	20.7***	22.1***	18.7***			15.1***
Collection costs for mixed waste (ln)[1]		-5.9***	-6.4***			-9.9***
Collection costs for separate waste fractions (ln)[1]		9.0***	9.1***			14.0***
Municipalities w/ ≤5,000 inhabitants[2]	-5.8***		-5.8***	-8.6***	-5.6***	-10.3***
Municipalities w/ ≥50,000 inhabitants[2]	-20.0***		-17.7***	-15.8***	-18.0***	-13.8***
Summary statistics						
N	6,900	28,925	26,466	20,679	55,609	10,621
R^2	0.41	0.32	0.36	0.16	0.09	0.36

Notes: P-values are indicated as follows: * p<0.10; ** p<0.05; *** p<0.01; the remaining variables are not significant; [1] These variables are expressed in natural logarithm; [2] Correspond to dummy (dichotomous) variables.

5.2.1.2 Analysis with panel data by NUTS of the explanatory variable 'kitchen waste'

To carry out a regional comparative analysis of the determinants of kitchen waste collection per capita, a model has been estimated for each level 1 of the NUTS territorial unit that optimises the results taking into account its explanatory power, the incorporation of significant variables and the number of observations. Table 34 presents the results of each model for each NUTS, where socio-economic, demographic and waste management variables are combined.

A certain homogeneity can be observed between the different regions with respect to the variables with significance that determine the collection per capita. In this sense, the dependent variable is determined in all regions by the following independent variables:

- Population, in the case of the municipalities of NUTS region NW (+)
- Population density (+), except for NUTS Central, where the results were not statistically significant
- Income per capita (+)
- Tourism activity, measured by the number of accommodations, in the case of the NUTS region NE (+)
- Total collection and treatment costs (+)

- Collection costs for mixed waste (-)
- Collection costs for separate waste fractions (+)
- Size of the municipality: 5,000 or less inhabitants (-)
- Size of the municipality: 50,000 or more inhabitants (-)

It should be noted that an independent variable that is not significant (non-effect on the dependent variable) in one specific defined model (including other variables), can be significant at the individual level (case of tourism activity) or in other designed models.

Despite the homogeneity in the results, important differences are also observed in terms of the degree of impact of each variable, determined by their respective coefficients. For example, the effect of income per capita is much higher in the municipalities of the Central region, while the same is true in the South/Insular region for the total costs variable.

Table 34. Results of the models estimated with panel data for the variable kitchen waste per capita by NUTS of Italy at the municipal level in the period 2010-2021

Independent variables	Models			
	1	2	3	4
	NUTS Central	NUTS NE	NUTS NW	NUTS S_Ins
Intercept (constant term)	-476.9***	-189.9***	-166.4***	-245.6***
Population (ln)[1]			3.1***	
Population density		0.003**	0.001***	0.002***
Foreign population				
Average age			1.1***	-1.3***
Ageing index	-0.03**			
Lower secondary education				
Taxable income per capita (ln)[1]	53.1***	23.9***	13.2***	28.8***
Employment rate				
Total accommodations per 1,000 inhabitants		0.2***		
Total collection and treatment costs (ln)[1]	8.7***	5.2***	5.7***	26.1***
Collection costs for mixed waste (ln)[1]	-9.7***	-7.5***	-4.5***	-6.5***
Collection costs for separate waste fractions (ln)[1]	16.5***	8.5***	5.4***	9.1***
Municipalities w/ ≤5,000 inhabitants[2]	-8.6***	-3.7***	-4.7***	-5.1***
Municipalities w/ ≥50,000 inhabitants[2]	-19.1***	-6.8**	-10.7***	-27.3***
Summary statistics				
N	3,566	6,770	9,985	6,294
R^2	0.31	0.28	0.31	0.34

Notes: P-values are indicated as follows: * p<0.10; ** p<0.05; *** p<0.01; the remaining variables are not significant; [1] These variables are expressed in natural logarithm; [2] Correspond to dummy (dichotomous) variables.

5.2.1.3 Analysis of the explanatory variable 'bio-waste'

According to the data presented in Table 35, in model 5, the set of independent variables explains 34% of the per capita collection of bio-waste for a total of 27,869 observations. Model 6, with an explanatory power of 48%, is estimated for 2,772 observations due to the absence of data on the incorporated variables. In any case, with respect to the observations considered, both models are representative for the whole of Italy.

The explanatory variables that significantly determine the bio-waste collection per capita are:

- Population (+)
- Population density (+)
- Foreign population (+)
- Average age (-)
- Income per capita (+)
- Tourism activity, measured by the number of accommodations and night stays (+)
- Total collection and treatment costs (+)
- Collection costs for mixed waste (-)
- Collection costs for separate waste fractions (+)
- Size of the municipality: 5,000 or less inhabitants (-)
- Size of the municipality: 50,000 or more inhabitants (-)

Table 35. Results of the models estimated with panel data for the bio-waste per capita variable for Italy at the municipal level in the period 2010-2021

Independent variables	Models					
	1	2	3	4	5	6
Intercept (constant term)	-318.9***	-501.0***	50.1***	-381.6***	-357.1***	-107.3*
Population (ln)[1]	8.4***	8.2***		4.0***	5.6***	
Population density	-0.006***	-0.007***		-0.008***	-0.004***	-0.008***
Foreign population	0.7***			0.8***	0.5***	1.0***
Average age	-1.5***	-1.8***		-1.4***	-1.3***	-1.3***
Lower secondary education	0.2***	0.3***				
Taxable income per capita (ln)[1]	30.8***	55.6***		46.0***	43.1***	15.6*
Employment rate	0.6***					0.8***
Total accommodations per 1,000 inhabitants	0.02	0.03				
Total nights at accommodations per 1,000 inhabitants				0.00009***		0.00007***

Independent variables	Models					
	1	2	3	4	5	6
Total collection and treatment costs (ln)[1]	20.5***	19.8***	12.2***	9.8***	12.3***	11.9***
Collection costs for mixed waste (ln)[1]				-9.5***	-6.8***	-14.0***
Collection costs for separate waste fractions (ln)[1]				17.4***	11.2***	21.8***
Municipalities w/ ≤5,000 inhabitants[2]	-6.0***				-7.8***	-20.8***
Municipalities w/ ≥50,000 inhabitants[2]	-32.0***				-28.4***	-11.9***
Municipalities w/ ≤5,000 inhabitants (compared to the baseline)[3]		6.2***		16.4***		
Municipalities w/ ≥50,000 inhabitants (compared to the baseline)[3]		-26.0***		-7.3*		
Summary statistics						
N	7,141	7,141	35,498	10,958	27,869	2,772
R^2	0.44	0.44	0.21	0.40	0.34	0.48

Notes: P-values are indicated as follows: * p<0.10; ** p<0.05; *** p<0.01; the remaining variables are not significant; [1] These variables are expressed in natural logarithm; [2] Corresponds to a dummy (dichotomous) variable; [3] These results correspond to the relative effects of different population sizes (≤5,000 and ≥50,000 inhabitants) are evaluated in relation to the baseline size (between 5,000 and 50,000 inhabitants).

5.2.2 Cross-sectional models

In this section, the results of the estimates for kitchen waste and bio-waste collection per capita in Italy are presented, using cross-sectional models for the year 2021.

5.2.2.1 Analysis of the explanatory variable 'kitchen waste'

Table 36 shows the results of the estimated cross-sectional models for kitchen waste collection per capita. In model 6, the independent variables explain 34% of the dependent variable for 3,440 municipalities. Model 2, which does not include cost variables, considers 6,188 municipalities and has an explanatory power of 27%. Waste management variables separately explain 15% of the dependent variable (model 4), while socio-economic and demographic variables explain 17% (model 3). The incorporation of the different NUTS regions as a dummy variable, i.e. one if it belongs to a given region and zero otherwise, makes it possible to check whether this territorial belonging is relevant. As the coefficients of these variables are significant and efficient, the relevance of belonging to one NUTS region or another on collection per capita cannot be rejected.

The explanatory variables that significantly determine the kitchen waste collection per capita are:

- Area of the municipality (-)
- Population (+)

- Population density (+)
- Low educational level (lower secondary education) (-)
- Tourism activity, measured by the number of accommodations (+)
- DtD collection (+)
- Open waste bins (-)
- Total collection and treatment costs (+)
- Collection costs for mixed waste (-)
- Collection costs for separate waste fractions (+)
- Size of the municipality: 5,000 or less inhabitants (-)
- Size of the municipality: 50,000 or more inhabitants (-)
- Municipality integrated into a NUTS level-1 region, excluding the South/Insular region (-)

Table 36. Results of the estimated cross-sectional models for the variable kitchen waste per capita in Italy at the municipal level for the year 2021

Independent variables	Models					
	1	2	3	4	5	6
Intercept (constant term)	-20.5	86.0***	513.5***	-93.8***	-20.6	-26.6**
Area	-0.04***	-0.06***	-0.04***		-0.04***	-0.07***
Population (ln)[1]	6.6***	2.7***	6.2***		6.6***	5.1***
Population density			-0.003***			
Foreign population	-0.6***		-0.7***		-0.6***	0.2*
Lower secondary education	-0.4***		-0.3***		-0.4***	
Taxable income per capita	-0.003***	0.0009***			-0.003***	
Taxable income per capita (ln)[1]			-47.1***			
Total accommodations per 1,000 inhabitants	0.7***	0.4***	0.4***		0.7***	0.7***
Door-to-door collection[2]	6.9***	2.3**		10.7***	7.2***	6.4***
Open waste bins[2]	-13.9***	-17.9***		-19.1***	-13.6***	-9.4***
Community waste bins[2]	-7.6					
Containers with controlled access[2]	-1.4					
Total collection and treatment costs (ln)[1]	22.2***			32.4***	22.1***	16.9***
Collection costs for mixed waste (ln)[1]	-5.4***			-2.2**	-5.4***	-6.4***
Collection costs for separate waste fractions (ln)[1]	6.8***			5.9***	6.8***	7.2***
Municipalities w/ ≤5,000 inhabitants[2]	-6.3***	-11.0***	-9.8***		-6.3***	-6.4***
Municipalities w/ ≥50,000 inhabitants[2]	-14.1***	-6.5**	-6.5*		-14.0***	-11.6***

Independent variables	Models					
	1	2	3	4	5	6
NUTS Central[2]		-13.6***				-14.8***
NUTS NE[2]		-32.4***				-28.9***
NUTS NW[2]		-39.8***				-37.1***
NUTS South/Insular[2,3]		*omitted*[3]				*omitted*[3]
Summary statistics						
N	3,440	6,188	6,674	3,441	3,440	3,440
R^2	0.28	0.27	0.17	0.15	0.28	0.34

Notes: P-values are indicated as follows: * p<0.10; ** p<0.05; *** p<0.01; the remaining variables are not significant; [1] These variables are expressed in natural logarithm; [2] Corresponds to a dummy (dichotomous) variable; [3] The model omits one of the NUTS (South/Insular) to avoid collinearity. The fact that the other coefficients of the NUTS variables are negative means that they have a lower collection rate than the NUTS South/Insular.

Table 37 shows the equivalent results to Table 36 after a more thorough filtration of outliers. With this operation, in model 6, the set of independent variables explains 44% of the kitchen waste collection per capita, i.e. it had a 10% increase in explanatory power. Model 4, with only the waste management variables, has an explanatory power of 17.7% and model 3, corresponding to the socio-economic and demographic variables, of 24.9%.

Table 37. Results of the cross-sectional models estimated for the kitchen waste per capita variable for Catalonia at the municipal level for the year 2021 (after eliminating the outliers)

Independent variables	Models					
	1	2	3	4	5	6
Intercept (constant term)	-4.7	47.0***	586.5***	-87.5***	-4.8	-18.7*
Area	-0.04***	-0.06***	-0.04***		-0.04***	-0.07***
Population (ln)[1]	6.8***	3.7***	5.7***		6.8***	5.3***
Population density			-0.002***			
Foreign population	-0.6***		-0.5***		-0.6***	0.3**
Lower secondary education	-0.4***		-0.6***		-0.4***	
Taxable income per capita	-0.004***	0.0008***			-0.004***	
Taxable income per capita (ln)[1]			-53.5***			
Total accommodations per 1,000 inhabitants	0.6***	0.4***	0.4***		0.6***	0.6***
Door-to-door collection	6.1***	1.0		10.0***	6.2***	5.5***
Open waste bins	-13.1***	-17.6***		-19.2***	-13.0***	-8.8***
Community waste bins	-6.4					
Containers with controlled access	0.7					
Total collection and treatment costs (ln)[1]	20.4***			31.9***	20.4***	15.9***
Collection costs for mixed waste (ln)[1]	-6.3***			-3.2***	-6.3***	-7.2***
Collection costs for separate waste fractions (ln)[1]	6.5***			5.4***	6.5***	6.8***

Independent variables	Models					
	1	2	3	4	5	6
Municipalities w/ ≤5,000 inhabitants[2]	-6.6***	-10.3***	-10.9***		-6.6***	-6.5***
Municipalities w/ ≥50,000 inhabitants[2]	-7.9**	-4.6*	-4.1		-7.9**	-5.6*
NUTS Central[2]		17.2***				-17.4***
NUTS NE[2,3]		*omitted*[3]				-30.7***
NUTS NW[2]		-7.4***				-38.5***
NUTS South/Insular[2,3]		32.7***				*omitted*[3]
Summary statistics						
N	3,234	5,825	5,825	3,234	3,234	3,234
R^2	0.37	0.37	0.25	0.18	0.37	0.44

Notes: P-values are indicated as follows: * p<0.10; ** p<0.05; *** p<0.01; the remaining variables are not significant; [1] These variables are expressed in natural logarithm; [2] Corresponds to a dummy (dichotomous) variable; [3] The model omits one of the NUTS (NE in model 2, and South/Insular in model 6) to avoid collinearity.

5.2.2.2 NUTS cross-sectional analysis of the explanatory variable 'kitchen waste'

The following section discusses a regional comparison of the determinants of kitchen waste collection per capita using cross-sectional data models for the year 2021. Specifically, two models have been estimated for each level 1 of the NUTS territorial unit, one with all the variables with significance and optimising the explanatory power and the other with waste management variables.

The results are presented in Table 38 for the municipalities of the central and NE NUTS and in Table 39 for the NUTS NW and South/Insular. In general, the explanatory power of NUTS models that incorporate all significant variables is lower than models for the country as a whole. This explanatory power is greater in the model estimated for the central NUTS, where exogenous variables explain 30% of the per capita collection of kitchen waste.

With regard to the determinants of per capita collection, there are common elements in the different NUTS that reinforce the conclusions of the other analyses carried out. In this sense, the dependent variable is significantly explained in all the NUTS by the following independent variables:

- DtD collection (+)
- Total collection and treatment costs (+)
- Collection costs for mixed waste (-)
- Collection costs for separate waste fractions (+), except for region NUTS Central
- Size of the municipality: 5,000 inhabitants or less (-), except for region NUTS S_Ins
- Tourism activity, measured by the number of accommodations (+), except for NUTS Central

Other relevant differences between groups of regions can be observed, indicating the utility of conducting an in-depth analysis in this direction. In this regard, these estimates should be considered as an initial and general analysis of regional differences in the determinants of kitchen waste collection per capita.

Table 38. Results of the estimated cross-sectional models for the variable kitchen waste per capita in Italy for the year 2021 for the municipalities of the central and NE NUTS

Independent variables	Models			
	1	2	3	4
	NUTS Central	NUTS Central	NUTS NE	NUTS NE
Intercept (constant term)	-654.3***	-122.1***	72.5***	62.8***
Area	-0.05**			
Population density			0.009**	
Ageing index	-0.08***			
Taxable income per capita (ln)[1]	65.3***			
Total accommodations per 1,000 inhabitants			0.6***	
Door-to-door collection[2]	8.9***	27.2***	8.5***	13.8***
Open waste bins[2]	-16.4**			
Containers with controlled access[2]	-21.8**			15.9*
Mixed collection[2]		20.4***	5.1	12.5***
Total collection and treatment costs (ln)[1]	35.6***	46.2***	-9.3*	-12.6***
Collection costs for mixed waste (ln)[1]	-10.0***	-14.0***	-8.3***	
Collection costs for separate waste fractions (ln)[1]			18.9***	18.8***
Municipalities w/ ≤5,000 inhabitants[2]	-7.8**		-9.5***	
Summary statistics				
N	495	496	753	755
R^2	0.30	0.18	0.23	0.13

Notes: P-values are indicated as follows: * p<0.10; ** p<0.05; *** p<0.01; the remaining variables are not significant; [1] These variables are expressed in natural logarithm; [2] Correspond to dummy (dichotomous) variables.

Table 39. Results of the estimated cross-sectional models for the variable kitchen waste per capita for Italy for the year 2021 for the municipalities of the NUTS NW and South/Insular

Independent variables	Models			
	5	6	7	8
	NUTS NW	NUTS NW	NUTS South/Insular	NUTS South/Insular
Intercept (constant term)	-29.5	7.1	-299.2***	-102.5***
Area			-0.08***	
Population (ln)[1]	3.9***		7.6***	
Population density			-0.004***	
Average age	1.1***		-1.5***	

Independent variables	Models			
	5	6	7	8
	NUTS NW	NUTS NW	NUTS South/Insular	NUTS South/Insular
Lower secondary education	-0.2**		0.5***	
Taxable income per capita (ln)[1]			24.7**	
Total accommodations per 1,000 inhabitants	1.0***		1.1**	
Door-to-door collection[2]	7.7***	6.3**	8.0*	8.4*
Open waste bins[2]	-6.0*	-6.9*		
Community waste bins[2]	45.9***	40.7***		
Total collection and treatment costs (ln)[1]	7.7***	14.9***	32.4***	41.2***
Collection costs for mixed waste (ln)[1]	-5.1***	-4.6***	-5.2***	-7.2***
Collection costs for separate waste fractions (ln)[1]			4.8***	4.7**
Municipalities w/ ≤5,000 inhabitants[2]	-4.7**			
Municipalities w/ ≥50,000 inhabitants[2]			-26.0***	
Summary statistics				
N	1,175	1,175	1,038	1,038
R^2	0.16	0.06	0.19	0.12

Notes: P-values are indicated as follows: * p<0.10; ** p<0.05; *** p<0.01; the remaining variables are not significant; [1] These variables are expressed in natural logarithm; [2] Correspond to dummy (dichotomous) variables.

5.2.2.3 Analysis of the explanatory variable 'bio-waste'

Table 40 shows the results of the estimated cross-sectional models for bio-waste collection per capita. In model 6, the independent variables explain 24% of the dependent variable for 3,538 municipalities, while in model 2 they explain 16% for 6,339 municipalities. In model 3, waste management variables separately explain 8%. On the other hand, in model 4, socio-economic and demographic variables explain 13% of the dependent variable.

The explanatory variables that significantly determine the bio-waste collection per capita are:

- Area of the municipality (-)
- Population (+)
- Population density (+)
- Low educational level (+)
- Tourism activity, measured by the number of accommodations (+)
- DtD collection (+)
- Open waste bins (-)
- Total collection and treatment costs (+)
- Collection costs for mixed waste (-)

- Collection costs for separate waste fractions (+)
- Size of the municipality: 50,000 inhabitants or more (-)
- Municipality integrated into a NUTS level-1 region, excluding the region NE (-)

Table 40. Results of the estimated cross-sectional models for the bio-waste per capita variable for Italy at the municipal level for the year 2021

Independent variables	**Models**					
	1	2	3	4	5	6
Intercept (constant term)	-62.2***	-34.1***	6.4	-35.8***	-144.0***	-146.1***
Area	-0.1***	-0.09***		-0.1***	-0.1***	-0.1***
Population (ln)[1]	12.0***	11.1***		14.3***	12.7***	11.5***
Population density	-0.006***	-0.006***		-0.008***	-0.01***	-0.008***
Foreign population	0.8***					
Average age	0.3				-1.6***	-1.6***
Lower secondary education	0.4***	0.4***		0.4***	0.5***	0.6***
Taxable income per capita	0.004***	0.004***		0.002***	0.003***	0.003***
Total accommodations per 1,000 inhabitants	0.3***			0.3***	0.3**	
Door-to-door collection	18.6**	14.5***	-2.2		16.6***	18.8***
Open waste bins	3.4		0.4		15.4**	12.5**
Community waste bins			-31.1***			
Containers with controlled access	5.5					
Mixed collection	11.3	7.7***			12.9**	11.6**
Total collection and treatment costs (ln)[1]			27.1***		31.3***	36.6***
Collection costs for mixed waste (ln)[1]			-16.9***		-10.0***	-10.3***
Collection costs for separate waste fractions (ln)[1]			7.9***		8.6***	8.0***
Municipalities w/ ≥50,000 inhabitants[2]	-17.6***	-16.4***		-19.7***	-22.1***	-20.4***
NUTS Central[2]	-14.2***	-5.3***				-23.7***
NUTS NE[2,3]	*omitted*	9.3***				*omitted*
NUTS NW[2]	-19.8***	-11.6***				-21.1***
NUTS South/Insular[2,3]	-4.3	*omitted*				-15.5***
Summary statistics						
N	6,339	6,339	3,540	6,844	3,538	3,538
R^2	0.16	0.16	0.08	0.13	0.21	0.24

Notes: P-values are indicated as follows: * p<0.10; ** p<0.05; *** p<0.01; the remaining variables are not significant; [1] These variables are expressed in natural logarithm; [2] Corresponds to a dummy (dichotomous) variable; [3] The model omits one of the NUTS (NE in models 1 and 6, and South/Insular in model 2) to avoid collinearity.

Table 41 shows the equivalent results to Table 40 after a more thorough filtration of outliers. Now, the set of independent variables explains 29% of the bio-waste collection per capita (model 6). Model 3, with only waste management variables, has an explanatory power of 8% and model 4, corresponding to socio-economic and demographic variables, of 19%. Consequently, the positive effects of data filtration mainly affect socio-economic and demographic variables.

Table 41. Results of the estimated cross-sectional models for the bio-waste per capita variable for Catalonia at the municipal level for the year 2021 (after eliminating the outliers)

Independent variables	**Models**					
	1	2	3	4	5	6
Intercept (constant term)	-79.3***	-46.7***	23.9**	-44.0***	-143.6***	-151.6***
Area	-0.1***	-0.1***		-0.1***	-0.1***	-0.1***
Population (ln)[1]	13.6***	12.8***		15.5***	14.2***	13.0***
Population density	-0.007***	-0.006***		-0.008***	-0.01***	-0.008***
Foreign population	0.5***					
Average age	0.3*				-1.2***	-1.2***
Lower secondary education	0.5***	0.5***		0.3***	0.5***	0.7***
Taxable income per capita	0.004***	0.004***		0.002***	0.003***	0.004***
Total accommodations per 1,000 inhabitants	0.2***			0.2***	0.2	
Door-to-door collection[2]	18.2**	14.2***	-2.3		17.6***	19.0***
Open waste bins[2]	2.9		-2.7		14.2**	11.2*
Community waste bins[2]			-29.3***			
Containers with controlled access[2]	6.6					
Mixed collection[2]	11.8	8.1***			14.9***	12.7**
Total collection and treatment costs (ln)[1]			23.1***		25.4***	30.0***
Collection costs for mixed waste (ln)[1]			-15.0***		-7.9***	-8.3***
Collection costs for separate waste fractions (ln)[1]			6.6***		7.2***	6.4***
Municipalities w/ ≥50,000 inhabitants[2]	-17.8***	-16.7***		-19.7***	-22.9***	-20.6***
NUTS Central[2]	-14.6***	-14.6***				-21.05***
NUTS NE[3]	*omitted*[3]	*omitted*[3]				*omitted*[3]
NUTS NW[2]	-20.9***	-21.7***				-22.0***
NUTS South/Insular[2]	-5.0**	-7.9***				-12.6***
Summary statistics						
N	6,011	6,011	3,359	6,011	3,359	3,359
R^2	0.23	0.23	0.08	0.19	0.25	0.29

Notes: P-values are indicated as follows: * p<0.10; ** p<0.05; *** p<0.01; the remaining variables are not significant; [1] These variables are expressed in natural logarithm; [2] Corresponds to a dummy (dichotomous) variable; [3] The model omits one of the NUTS (NE) to avoid collinearity. The fact that the other coefficients of the NUTS variables are negative means that they have a lower collection rate than the NUTS NE.

5.2.3 Result of the standardised coefficients for the main models estimated for Italy

Table 42 and Table 43 show the results of the estimation of the main models of each category using standardized coefficients for Italy. This facilitates the comparison between the coefficients of the various independent variables and allows the assessment of the impact of each one on the per capita collection in each model. It is important to note that the coefficients obtained from the panel and cross-sectional data models are not directly comparable, due to the structural and methodological differences between both types of models. Table 42 presents the results of the optimal model for panel data, while Table 43 includes those for cross-sectional models. Each table indicates the model that has been used to estimate the standardized coefficients and that coincides with the estimated optimal model of each type.

Table 42. Estimated standardised coefficients of the main models with panel data for Catalonia

Independent variables (standardized)	**Models**	
	Kitchen waste (No 3)	**Bio-waste** (No 5)
Population (ln)[1]	6.3	7.6
Population density	*N.A.*[1]	-2.5
Foreign population	-3.2	2.3
Average age	1.3	-4.7
Taxable income per capita (ln)[1]	-5.9	11.8
Total accommodations per 1,000 inhabitants	5.3	*N.A.*[1]
Total collection and treatment costs (ln)[1]	5.8	3.8
Collection costs for mixed waste (ln)[1]	-4.5	-4.8
Collection costs for separate waste fractions (ln)[1]	9.1	6.5
Municipalities w/ ≤5,000 inhabitants[2]	-2.7	-3.6
Municipalities w/ ≥50,000 inhabitants[2]	-2.3	-3.8

Notes: [1] This variable is expressed in natural logarithm; [2] Correspond to dummy (dichotomous) variables; N.A. stands for non-available data. There are no estimates for these variables due to insufficient data or its lack of statistical significance.

Table 43. Estimated standardized coefficients of the main models with cross-section data for Italy

Independent variables (standardized)	**Models**	
	Kitchen waste (No 6)	**Bio-waste** (No 6)
Area	-0.1	-0.1
Population (ln)[1]	0.2	0.3
Population density	*N.A.*[1]	-0.1
Foreign population	0.03	*N.A.*[1]
Average age	*N.A.*[1]	-0.1
Lower secondary education	*N.A.*[1]	0.1

Independent variables (standardized)	Models	
	Kitchen waste (No 6)	**Bio-waste** (No 6)
Taxable income per capita	*N.A.*[1]	0.2
Total accommodations per 1,000 inhabitants	0.2	*N.A.*[1]
Door-to-door collection[2]	0.08	0.2
Open waste bins[2]	-0.07	0.07
Mixed collection[2]	*N.A.*[1]	0.1
Total collection and treatment costs (ln)[1]	0.1	0.2
Collection costs for mixed waste (ln)[1]	-0.1	-0.2
Collection costs for separate waste fractions (ln)[1]	0.1	0.1
Municipalities w/ ≤5,000 inhabitants[2]	-0.09	*N.A.*[1]
Municipalities w/ ≥50,000 inhabitants[2]	-0.06	-0.08
NUTS Central[2]	-0.1	-0.2
NUTS NE[2]	-0.3	_
NUTS NW[2]	-0.5	-0.2
NUTS South/Insular[2]	_	-0.2

Notes: [1] This variable is expressed in natural logarithm; [2] Correspond to dummy (dichotomous) variables; N.A. stands for non-available data. There are no estimates for these variables due to insufficient data or its lack of statistical significance.

5.2.4 Analysis of the South/Insular Italy

This section presents the results of the estimated models for the per capita collection of kitchen waste in the NUTS South/Insular of Italy. The analysis is carried out for a total of 1,790 municipalities. First, the comparative impact of the DtD service on kitchen waste collection between 2010 and 2021 is estimated. Secondly, a statistical comparison is made between the evolution of the municipalities that, in 2010, were considered pioneers (i.e. those that exceeded 70 kg of per capita collection of kitchen waste) and the municipalities that reached this threshold in 2018.

5.2.4.1 Comparative impact between 2010 and 2021 of the DtD service on kitchen waste collection

The aim of the analysis is to assess the comparative impact, between 2010 and 2021, of the implementation of the DtD service on the separate collection of kitchen waste per capita in municipalities in South/Insular Italy. The hypothesis that is to be statistically tested is whether the effect of the DtD service has been more important in the municipalities that installed it in 2021 compared to those that implemented it in 2010, in their respective year.

For this purpose, a DiD model has been used, which is estimated in the form of linear regression, where the dependent variable is the kitchen waste collection per capita and the independent variables are:

- D2D2010: It is a dichotomous variable (0 or 1), which takes a value of 1 if the municipality implemented the DtD service in 2010 (0 otherwise).

- D2D2021: It is a dichotomous variable that takes a value of 1 if the municipality implemented the DtD service in 2021 (0 if it implemented it before or if it did not implement it).
- D2D: A variable that takes a value of 1 if the DtD service was operational in 2021, regardless of when it was installed (0 otherwise).
- 2021Year: This is the effect of 2021 on the general variation in collection per capita regardless of the DtD service.
- D2D2021in2021vs2010: It is an interaction variable that evaluates whether the effect of installing the DtD service in 2021 is different from that of the municipalities that did so in 2010.

The DtD model is estimated, in parallel, through two equations to avoid collinearity problems. In equation (1) the independent variables are D2D2010, D2D2021 and 2021Year and in equation (2) they are 2021Year and D2D2021in2021vs2010. Table 44 presents the results of the two estimated equations. Among the most outstanding findings, the following are noted:

- The independent variables used in the estimated models explain 17% of the per capita collection of kitchen waste and all the variables are statistically significant.
- The value of the coefficient of D2D2010 is 48.1. This indicates that the municipalities that implemented the DtD service in 2010 collected 48.1 kg of kitchen waste per capita more compared to those that did not have DtD system in that year.
- The value of the D2D2021 coefficient is 15.0. This implies that the municipalities that implemented the DtD service in 2021 collected 15.0 more kg of kitchen waste per capita than those that did not implement DtD, or that already had it before 2021.
- The value of the coefficient of 2021.Year is 42.9. That is, overall, kitchen waste collection was 42.9 kg per capita higher in 2021 than in 2010, suggesting that per capita collection increased over time, regardless of the DtD service.
- The value of the interaction coefficient D2D2021in2021vs2010.Year is -33.1. This indicates that the interaction between having the DtD service in 2021 and the growth in kitchen waste collection per capita of 2021 with respect to this same relationship in 2010, has a negative effect of -33.1 kg per capita. This implies that the additional impact of the implementation of the DtD collection model in 2010 was greater than in 2021 (compared to those that did not have DtD system in that year), even though the overall level of collection rates was higher in 2021. Therefore, the relative effect of the DtD service was stronger in municipalities that pioneered its implementation in 2010 compared to those that introduced it in 2021.

In summary, the effect of the DtD service has been positive in both 2010 and 2021, but this impact is more important, in terms of increasing kitchen waste collection per capita, in 2010 than in 2021.

Simply put, even early frontrunners in "wild west" can have high results - not only compared to those who didn't implement but also compared to those who started years later with much more knowledge and other surrounding implementers.

Table 44. Results of the comparative effects of the DtD service between 2010 and 2021 in the municipalities of the South/Insular regions of Italy

Independent variables	(1)	(2)
Intercept (constant term)	49.3***	49.3***
D2D2010	48.1***	
D2D2021	15.0***	
2021.Year	42.9***	42.9***
D2D		48.1***
D2D2021in2021vs2010a		-33.1***
Summary statistics		
N	2,137	2,137
R^2	0.17	0.17

Note: P-values are indicated as follows: * p<0.10; ** p<0.05; *** p<0.01; the remaining variables are not significant.

5.2.4.2 Analysis of the growth in kitchen waste collection of the pioneer municipalities in 2010 compared to the rest of the municipalities

This section statistically compares the evolution of the municipalities that were pioneers in 2010, that is, those that had a kitchen waste collection per capita of more than 70 kg,[1] with respect to those that exceeded this amount in 2018. Specifically, the objective is to test the hypothesis of whether the pioneer municipalities had a growth in kitchen waste collection per capita in the first years (2010 - 2013) higher than the growth until 2021 of those municipalities that exceeded 70 kg in 2018.

Therefore, the null hypothesis to be tested is that there is no difference in the growth of kitchen waste collection per capita between the pioneers of 2010 and the municipalities that in 2018 exceeded the amount of 70 kg per capita. The alternative hypothesis is whether the growth in kitchen waste collection of the pioneers in 2010 was lower. The contrast is carried out by performing a T-test to compare the means of the growth in kitchen waste collection of the two groups. In this test, the aim is to test whether there is sufficient evidence to reject the null hypothesis, and this happens when the p-value is low (less than 0.10),

[1] According to the 2024 BIC & ZWE report "Bio-waste generation in the EU: Current capture levels and future potential," the capture of efficient collection models is 60-100 kg/inhab. For this specific analysis, 70 kg/inhab. was selected as the average threshold(Favoino & Giavini, 2024).

indicating that the observed difference is not due to chance. The results of the T-test are presented in Table 45.

The results indicate that the growth in the kitchen waste collection of pioneers from 2010 to 2013 follows an average of 6.2 kg of kitchen waste per capita, while that of those who in 2018 exceeded 70 kg is 5.6 kg. The result of the statistical contrast of the null hypothesis is not significant, since the p-value is 0.3 (greater than 0.1), so the hypothesis that there is no difference in the growth of kitchen waste collection per capita between the pioneers of 2010 and the rest cannot be rejected.

Table 45. Results of the statistical contrast on whether the growth of the pioneer municipalities in 2010 is significantly different from the rest

Municipalities w/ kitchen waste collection > 70kg	Observations	Mean
Municipalities (2010)	962	6.2
Municipalities (2018)	3,229	5.6
Total	4,191	5.7
Difference	-	0.6
P-value	-	0.3

To conceptualize this result in terms of management and practical experience, with a view to policy and governance recommendations, it can be concluded that the municipalities that in 2010 were really "pioneers" achieved very good results despite introducing a model that at that time was not well-established in the territory and there were not so many references and know-how.

Before this analysis, one might think that in situations of relatively low general interest (national, regional) in the issue of bio-waste collection, those who started did so with little success and citizens did not participate in separate collection as actively as those who introduced DtD later (2021) when it was already a model with wide coverage and acceptance. Without this analysis, a priori, common sense pointed in the opposite direction to the fact that the latter, feeling surrounded and "pressured" by the type of model and the already good results of others, and greater civility, had to achieve better results.

On the contrary, statistics show that the pioneering municipalities managed to involve citizens well and possibly more than those that started later. The willingness and commitment of early frontrunners was an impacting factor of success, more if it is considered the unfavorable context with low landfilling costs and week governance scheme in the region. This is a key conclusion when planning national strategies in European regions that are still far from achieving effective models and good results. This focuses on the role of frontrunners as a beacon of good practices and important reference for others.

6 Summary of the main results

In general, for the set of variables, cross-sectional models have greater explanatory power and generate slightly more precise estimates than panel data models. This is mainly due to the greater availability of data and the absence of problems related to the temporal evolution of variables, such as the dependence of the value of a variable in one year on its value in previous years. However, it is worth remembering that the effects of variables over time are being ignored in the case of cross-sectional models, which can be important. Therefore, the greater precision of the second type of models only corresponds to the analysis between municipalities, but not over time.

For all estimated models, with the information on the independent variables used in the analyses, these explain a slightly higher percentage of the per capita collection of kitchen waste than of bio-waste. It should be considered that bio-waste, by including the garden fraction, may lead to greater seasonal variability depending on the type of housing and weather conditions.

In all the estimated models, the independent waste management variables[2] explain a higher amount of collection per capita than the rest of the socio-economic and demographic variables. Furthermore, the estimated effects of waste management variables are more precise and statistically reliable. Below is a summary of the main results of the statistical analysis with a communicative approach.

6.1 Main results from Catalan analysis

In the case of Catalonia, all estimates are made for the collection per capita of kitchen waste and bio-waste for all municipalities and, separately, for those with a population of less than 5,000 inhabitants.

Table 46 presents a summary of the results obtained, for the different types of estimated models (with panel data and cross-sectional data), regarding the incidence of the analysed variables on kitchen waste and bio-waste collection per capita for Catalonia. In order to improve clarity in the presentation of the results, it is indicated for each independent variable whether its estimated impact on collection is high, medium or low intensity. The intensity of the effect reflects the degree of impact that each independent variable has on per capita collection. This is measured by the numerical value associated with each independent variable, also known as the coefficient value, in a regression equation (for more information, see section 5). It is also indicated whether this effect is generated in the same direction, that is, if an increase in the independent variable generates an increase in collection (+ sign of the value) or vice versa (- sign of the value).

[2] Except in the analysis of bio-waste collection per capita for municipalities with less than 5,000 inhabitants in Catalonia.

Table 46. Main results of the optimal models of each type of analysis carried out for Catalonia

Dependent variables	Independent variables	Models with data panel		Models with cross-sectional data	
		All municipalities	Municipalities with <5,000 inhab.	All municipalities	Municipalities with <5,000 inhab.
Period		2010-2021		2021	
Collection of kitchen waste (kg/inhab./yr)	Area	n.d.	n.d.	+	-
	Population	n.d.	n.d.	++	++
	Population (municipalities w/ ≤5,000 inhab.)*	n.d.	n.d.	++	n.d.
	Population (municipalities w/ 5,001 to 50,000 inhab.)*	n.d.	n.d.	++	n.d.
	Population (municipalities w/ ≥50,000 inhab.)*	-	n.d.	n.d.	n.d.
	Population density	-	+	-	n.d.
	Average age of the population	++	+	++	++
	Population with only primary education	+	n.d.	n.d.	n.d.
	Average net income per person	++	+	n.d.	n.d.
	Unemployed population	n.d.	n.d.	-	-
	Gini index for inequality	n.d.	-	n.d.	n.d.
	Total accommodations per 1,000 inhab.	---	--	-	-
	Door-to-door collection model*	+++	+++	+++	+++
	Containers with controlled access*	n.d.	n.d.	++	++
Collection of bio-waste (kg/inhab./yr)	Area	n.d.	n.d.	-	-
	Population (municipalities w/ ≤5,000 inhab.)*	+++	n.d.	+	n.d.
	Population (municipalities w/ ≥50,000 inhab.)*	---	n.d.	n.d.	n.d.
	Population (municipalities w/ 5,001 to 50,000 inhab.)*	n.d.	n.d.	++	n.d.
	Population density	--	+	-	n.d.
	Population with only primary education	-	-	-	n.d.
	Population with tertiary education	++	++	n.d.	n.d.
	Average net income per person	++	++	+	+
	Total accommodations	n.d.	n.d.	+	n.d.
	Total accommodation per 1,000 inhab.	-	-	n.d.	n.d.
	Door-to-door collection model*	+++	+++	+++	+++
	Containers with controlled access *	n.d.	n.d.	+	++

*Legend: "+" or "-"; "++" or "--" and "+++" or "---" indicate, respectively, a low, medium and high impact of the independent variable on per capita collection. The positive sign, represented in different shades of green according to its intensity, indicates that the effect is produced in the same direction; that is, an increase in the independent variable implies an increase in per capita collection. The negative sign, representing shades of yellow-orange, indicates that an increase in the independent variable implies a decrease in per capita collection; "n.d." stands for "no data". This means that there are no resulting data for this variable since it has not been estimated in this model due to lack of data or because it is not statistically significant; * correspond to dummy variables.*

Table 47. Summary of statistical results for Catalonia for kitchen waste and bio-waste based on variables

Variable	Kitchen waste	Bio-waste
Collection model - DtD	In comparison with the other collection models, the DtD model has a high impact on increasing collection, which is evident in all estimated models. The presence of containers with controlled access is also associated with an increase in kitchen waste collection, although with a medium impact and only for 2021, the year for which data is available.	Like kitchen waste results, DtD and containers with controlled access models for bio-waste have a positive impact with medium-high intensity. It should be noted that, regarding the containers with controlled access collection model, only 18 small municipalities had implemented it in 2021.
Population	Municipalities with a population greater than 50,000 inhabitants collect less kitchen waste per capita compared to smaller municipalities so higher population has a negative impact on kitchen waste collection.	With a high level of impact, municipalities with less than 5,000 inhabitants obtain a higher bio-waste collection per capita. This effect is the opposite in municipalities with a population of more than 50,000 inhabitants.
Population density	Greater population density in municipalities with less than 5,000 inhabitants, although with a low level of impact, is related to a higher kitchen waste collection per capita. On the other hand, in the rest of the municipalities, population density is associated with a decrease in collection.	Like kitchen waste results, a higher population density positively affects the collection of bio-waste in municipalities with less than 5,000 inhabitants and negatively in the rest.
Tourism	Municipalities with greater tourist activity are generally associated with lower kitchen waste collection. This impact is more significant in municipalities with a population of more than 5,000 inhabitants and in the analyses carried out for the period 2010-2021, compared to the models estimated for the year 2021.	More tourist activity in the municipality is related to a slight decrease in bio-waste collection per capita. Therefore, the effect of tourism activity on the collection per capita of bio-waste is substantially less intense than that generated on the collection of kitchen waste.
Income level	Higher levels of income per capita are associated with a medium positive impact on the increase in kitchen waste collection per capita.	Like kitchen waste results, higher levels of income per capita are associated with a medium positive impact on bio-waste collection per capita.
Other variables	Higher values of average age per capita are associated with a	Higher levels of population with a low level of education are related, with a low

Variable	Kitchen waste	Bio-waste
	moderate positive impact on the increase in kitchen waste collection per capita. Greater social inequality (measured by the Gini Index) and higher unemployment are related, with a low impact, to lower kitchen waste collection per capita.	impact, to a lower bio-waste collection per capita.
Specific analysis of municipalities with less than 5,000 inhabitants	Panel data: for both types of flows (kitchen waste and bio-waste), some differences are observed in terms of the sign and intensity of the impact of some independent variables, which indicates the differential nature of this group of municipalities in relation to the municipalities with the largest population. A difference to highlight is that the existence of a DtD collection model or containers with controlled access has a relatively greater impact on these municipalities with a smaller population. Cross sectional: the percentage explained by the independent variables regarding the level of kitchen waste collection per capita is higher compared to the analysis that considers all municipalities. The opposite occurs with bio-waste collection per capita.	

The theoretical results coming from the statistical analysis (see table above) may be supported by empirical know-how and experience from the management schemes and practices in Catalonia. The following takeaways were then extracted.

The DtD model, which is able to individualize the participation and monitor quality, has a high impact on increasing bio-waste collection in quality and quantity. In the field, the municipalities with this type of model represent the best management practices and results. The nascent results from containers with controlled access models must be considered with caution since they come from a limited sample of small Catalan municipalities.

In Catalonia, small municipalities have been pioneers and front-runners of the implementation of more advanced models such as DtD, especially municipalities under 20,000 inhabitants. Reduced size and low density make the implementation of DtD more feasible (for more information, see **LIFE BIOBEST D2.3 Assessment Matrix of Best Practices** and **LIFE BIOBEST D3.1 Guideline on separate collection**). Within the stated context, this is why the specific analysis considering the size of the municipalities results in higher collection per capita for municipalities below 5,000 inhabitants. This contrasts with larger municipalities (more than 50,000 inhabitants), where there is a negative relationship between population/population density and collection since, in general, they rely on open containers.

Bio-waste generation per capita (e.g. residents) is typically high in touristic areas because it includes the quantities generated by touristic establishments and visitors. Despite this, there is a negative impact of high tourism levels in material capture that can be explained by the fact that these Catalan local entities, especially coastal, have more complex bio-waste management and seasonal fluctuations (due to seasonal population changes, economic activity related to tourism, etc. For more information, see **LIFE BIOBEST D2.3 Assessment Matrix of Best Practices**). In addition, there is a more widespread use of open containers in these municipalities, which are not able to capture high rates of kitchen waste. As mentioned, this effect is more evident in larger municipalities.

As a final conclusion, social inequality and higher unemployment may be associated with lower collection per capita, since the users may be focused on other domestic problems. A similar effect occurs in the analysis related to populations with a low level of education. In these cases, models that monitor participation such as DtD, paired with intense communication actions and continuous services, can work as a positive solution to increase the capture rates. The opposite occurs in local entities with a higher income level where higher participation in the bio-waste collection service is observed.

6.2 Main results from Italian analysis

For the case of Italy, with the aim of analyzing the determinants of the kitchen waste and bio-waste collection per capita, models have been estimated with panel and cross-sectional data for the same independent variables as for Catalonia as well as different types of waste management costs. The main unit of analysis is the municipality. Additionally, a joint analysis was carried out comparing regions according to the Nomenclature of Territorial Statistical Units (NUTS) level 1 regions: Northwest (NW), Northeast (NE), Centre, South/Insular. This comparative and complementary analysis was only carried out for the dependent variable of kitchen waste collection per capita.

In addition, the regions of South/Insular Italy have been analysed in order to compare, firstly, the impact on the collection of kitchen waste from the DtD service between 2010 and 2021 and, secondly, to analyse whether there are significant statistical differences between municipalities that, in 2010, were considered pioneers because their kitchen waste collection per capita exceeded 70 kg and the municipalities with later implementation of DtD that reached this threshold in 2018.

Table 48 presents a summary of the results obtained, for the different types of estimated models (with panel data and cross-sectional data), regarding the incidence of the analysed variables on kitchen waste and bio-waste collection per capita for Italy. In order to improve clarity in the presentation of the results, it is indicated for each independent variable whether its estimated impact on collection is high, medium or low intensity. The intensity of the effect reflects the degree of impact that each independent variable has on per capita collection. This is measured by the numerical value associated with each independent variable, also known as the coefficient value, in a regression equation (for more information, see section 5). It is also indicated whether this effect is generated in the same direction, that is, if an increase in the independent variable generates an increase in collection (+ sign of the value) or vice versa (- sign of the value).

Table 48. Main results of the optimal models of each type of analysis carried out for Italy

	Dependent variables	Collection of kitchen waste (kg/inhab./year)		Collection of bio-waste (kg/inhab./year)	
	Type of model	Models with data panel	Models with cross-sectional data	Models with data panel	Models with cross-sectional data
	Period	2010-2021	2021	2010-2021	2021
Independent variables	Area	n.d.	--	n.d.	--
	Population	++	+++	+++	+++
	Population (municipalities w/ ≤5,000 inhab.)*	-	-	-	n.d.
	Population (municipalities w/ ≥50,000 inhab.)*	-	-	-	-
	Population density	n.d.	n.d.	-	--
	Foreign population	-	-	+	n.d.
	Average age	+	n.d.	--	-
	Lower secondary education	n.d.	n.d.	n.d.	++
	Taxable income per capita	--	n.d.	+++	+++
	Total accommodations per 1,000 inhab.	++	+++	n.d.	n.d.
	Total collection and treatment costs	++	+++	+	+++
	Collection costs for mixed waste	--	---	n.d.	n.d.
	Collection costs for separate waste fractions	+++	+++	+++	+
	Door-to-door collection model*	n.d.	+++	n.d.	+++
	Open waste bins*	n.d.	--	n.d.	+
	Mixed collection*	n.d.	n.d.	n.d.	++
	NUTS level 1 – Central Italy	n.d.	--	n.d.	---
	NUTS level 1 – Northeast Italy	n.d.	---	n.d.	+++
	NUTS level 1 – Northwest Italy	n.d.	---	n.d.	---
	NUTS level 1 – South/Insular Italy	n.d.	+++	n.d.	--

*Legend: "+" or "-"; "++" or "--" and "+++" or "---" indicate, respectively, a low, medium and high impact of the independent variable on per capita collection. The positive sign, represented in different shades of green according to its intensity, indicates that the effect is produced in the same direction; that is, an increase in the independent variable implies an increase in per capita collection. The negative sign, representing shades of yellow-orange, indicates that an increase in the independent variable implies a decrease in per capita collection; "n.d." stands for "no data". This means that there are no resulting data for this variable since it has not been estimated in this model due to lack of data or because it is not statistically significant; * correspond to dummy variables.*

Similar to the Catalan analysis, Table 49 presents a summary of the results of the different types of estimated models (with panel data and cross-sectional data), regarding the incidence of the different variables analysed on the kitchen waste and bio-waste collection per capita in Italy.

Table 49. Summary of statistical analysis results for Italy for kitchen waste and bio-waste based on variables

Variable	Kitchen waste	Bio-waste
Collection model - DtD	DtD model application, for which data is only available for 2021, reveals a high positive impact on kitchen waste collection per capita. On the other hand, the model based on open waste bins has the opposite effect, with a medium negative impact level.	DtD model application, for which data is only available for 2021, has a high positive impact on bio-waste collection per capita. Models based solely on open waste bins or in combination with the DtD system (mixed collection) present the same effect, although with a low and medium intensity impact, respectively.
Population	Increases in population are associated with greater kitchen waste collection per capita. Municipalities with less than 5,000 inhabitants and those with 50,000 or more inhabitants are associated with lower kitchen waste collection per capita, with a low level of negative impact of the variable.	Like kitchen waste results, increases in population are associated with greater bio-waste collection per capita. Municipalities with less than 5,000 inhabitants and those with 50,000 or more inhabitants tend to have a lower bio-waste collection rate per capita, with a low level of negative impact of the variable.
Population density	No significant results.	Municipalities with higher population density are associated with lower bio-waste collection per capita.
Tourism	Municipalities with higher tourism levels are associated with greater kitchen waste collection per capita.	No significant results.
Income level	Higher average income per capita in municipalities is associated with lower kitchen waste collection per capita levels.	Higher average income per capita in municipalities has a high impact on increasing bio-waste collection per capita.
Average age	Municipalities with greater average age are associated with, although at a low intensity, greater kitchen waste collection per capita.	Municipalities with greater average age are associated with lower bio-waste collection per capita.
Costs	Higher total cost of waste collection and treatment is associated with higher kitchen waste collection per	Higher total cost of waste collection and treatment, as well as cost of separate waste fractions cost, are associated

Variable	Kitchen waste	Bio-waste
	capita. Specifically, a higher collection cost for separate waste fractions is associated with greater collection, while the opposite is true for collection costs for mixed waste (see additional conclusion on cost variables below).	with higher bio-waste collection per capita.
NUTS	According to data available for the year 2021, a municipality that belongs to the NUTS Central, NE and NW regions is associated with lower kitchen waste collection per capita compared to the NUTS South/Insular regions.	According to data available for the year 2021, a municipality that belongs to the NUTS Central, South/Insular or NW region is associated with lower bio-waste collection per capita compared to the NUTS NE.
Early frontrunners	In the South/Insular regions of Italy, the application of DtD collection for kitchen waste has had a positive and relevant impact in both 2010 and 2021, being substantially more important in 2010 than in 2021. In the South/Insular regions of Italy, there are no statistically significant differences in the growth in the first years of the pioneering municipalities in 2010 (municipalities that exceeded 70 kg of collection per capita that year) compared to those that exceeded this amount in 2018 and 2019.	No significant results.

Some additional considerations regarding the main conclusions from some specific variables and specific analysis carried out for Italy:

Panel Data-Cost variable:

- In the analyses carried out for both types of waste, the cost variables of waste collection and treatment explain a much higher percentage of collection per capita than the socio-economic and demographic variables. That is, this type of variable exhibits a stronger correlation with per capita bio-waste collection. Especially, this stronger correlation between variables is observed in the variable of collection costs for separate waste fractions. However, due to the characteristics of the cost variables, it is important to note that, in general, they can present a situation of reverse causality. That is, the independent variables of management costs could depend on the dependent variable of the model, collection per capita. This can impair the quality of the analyses. This relationship must be studied more in depth, but in the scope of this study we can provide the general empirical know-how that major investment in good quality and effective collection services results in a higher participation rates in separate collection, especially using individualized models.

Panel Data-NUTS analysis:

- In general, the percentage that the independent variables explain the level of kitchen waste collection per capita in the different NUTS regions is very similar, being slightly lower in the NUTS Northeast.
- A homogeneity can be observed between the different NUTS with respect to the variables that determine the kitchen waste collection per capita. However, important differences are observed in terms of the intensity of impact of each variable. For example, the impact of income per capita is significantly stronger in municipalities located in the NUTS 'Central' region, while the total costs have a greater effect in municipalities of the NUTS South/Insular regions.

Cross-sectional-NUTS analysis:

- The inclusion in the general models of different NUTS territorial dummy variables is statistically relevant to understanding waste collection. This approach helps account for regional factors that may influence waste collection practices, improving the overall explanatory power of the models.
- In the specific submodels built by NUTS, the percentage explained by the variables incorporated in the estimates is lower than in the models for the country as a whole. This explanatory power is greater in the estimates for the NUTS Center and Northeast.
- Other relevant differences can be observed by groups of NUTS, which indicates that an in-depth analysis in this direction could be interesting. In this sense, these estimates should be considered as an initial and general analysis of regional differences in the determinants of kitchen waste collection per capita.

The theoretical results coming from the statistical analysis (see table above) may be supported by empirical know-how and experience from the management schemes and practices in Italy. By making a contextual assessment of the study results with the Italian partners of the LIFE BIOBEST project, some relevant information was extracted that allows to be contextualized within the framework of the practical management experience and the thousands of Italian municipalities that already have good results.

Apart from the relationships that are understood without further explanation (e.g. it is empirically known that dedicating more costs to collecting the residual fraction causes less organic capture, since the frequency and volume collected has a bias towards the residual fraction), some peculiarities are observed. Firstly, it is confirmed that the DtD model allows a greater capture of kitchen waste due to its convenience and ease in promoting a rapid and consolidated change of habits. This is especially true in cities with 5,000 to 50,000 inhabitants. The collection per capita increases with the population because it is easier to implement optimized and homogeneous systems with respect to rural areas with very low and dispersed populations.

Regarding the complementary analyses considering the NUTS and the largest proportion of kitchen waste in the regions of South/Insular Italy and islands, according to experience, it is due to the widespread habit of preparing food at home, compared to the "faster" food consumed in centralized places (work, restaurants, etc.) in the northern regions.

The context and dynamics of tourist areas (number of accommodations) do not have a negative effect, but on the contrary, in these areas more efficient collection models were developed without problems because good practices of long experience with DtD systems for many years could be copied, added to the greater generation of kitchen waste derived from the seasonal population.

The history and results from the pioneers is noteworthy because, as in line with the explanation in section 5.2.4, the pioneer frontrunners who started many years ago with the separate collection of kitchen waste in complex areas such as South/Insular Italy, managed to involve the public, possibly more than those who started separate collection later. The commitment and political will of these municipalities was crucial, compensating for the fact that they were not surrounded by other municipalities with similar management. Local entities that started later, on the contrary, had more reference points, which are important when planning national strategies in European regions that are still a long way from achieving good results over a wide area and with efficient and consolidated models.

6.3 Comparison between analyses of Catalonia and Italy

When comparing the results of the econometric analyses carried out for Catalonia and Italy, with similar bio-waste management models regarding materials requested, Ho.Re.Ca. involvement in the municipal system and green fraction collection, several noteworthy elements are revealed, in relation to the factors that influence the kitchen waste and bio-waste collection per capita in the municipalities of both territories.

- In both territories, cross-sectional models for the year 2021 have greater explanatory power and accuracy than panel data models.
- In general, econometric analyses on kitchen waste are more accurate and better explain the factors influencing collection, compared to those of bio-waste. Models for kitchen waste are slightly more consistent and efficient, which means that the results obtained are more reliable and robust. This means that these models help to better understand the key variables that affect the collection of this waste.

Table 50. Effects on bio-waste/kitchen waste collection capture per capita of the different variables

Variable	Catalonia	Italy
Collection model - DtD	High positive impact.	High positive impact.
Population	Positive impact for medium and small municipalities, and negative impact for larger municipalities with population >50.000 inhab.	Increases in population are associated with positive impact, in general. Negative impact for larger populations.
Population density	Positive impact for small municipalities (less than 5,000 inhab.), and negative impact for larger municipalities.	Negative impact (results not differentiated by municipal population size).
Tourism	Negative impact, more intense with population >5.000.	Positive impact (considering more effective collection schemes in place).
Income per capita	Positive impact.	Positive impact.

7 Conclusions

Regarding the econometric analysis carried out, the main conclusions include:

- This study has statistically tested, through econometric models, the determinants of per capita collection of kitchen waste and biowaste in Catalonia and Italy. To achieve this, various models have been developed, demonstrating the significance of these variables in municipal-level waste collection. In this regard, this work serves as a starting point for future analyses that further explore the intensity of the effects of these variables in different contexts, which can be highly useful for designing local waste management policies.

- This work has demonstrated the potential of econometric models of panel and cross-sectional data for the analysis of the determinants of kitchen waste and bio-waste collection per capita at the municipal level. One of the key advantages of panel data models lies in their ability to control particular unobserved characteristics of each municipality, such as cultural, historical, or political aspects, allowing structural differences to be better captured over time. This translates into greater accuracy in the analysis, as the models can distinguish between factors that vary between municipalities and factors that uniformly affect all municipalities during the study period.

- On the other hand, cross-sectional models have also shown their usefulness, especially in identifying specific patterns and relationships in a specific year, without the added complexity of temporal variations. These models have offered clearer and more efficient analysis due to the greater volume of data available and the absence of temporal complications, allowing for a more focused and robust analysis of key determinants.

- Overall, the combined use of these econometric approaches represents a significant methodological advance for this type of study. The results obtained offer a stronger basis for understanding how different factors, such as waste management, socio-demographic characteristics and local policies, affect the collection of kitchen waste and bio-waste. In addition, these econometric models allow regional variabilities to be explored and offer a versatile analytical framework for future comparative studies or cluster analysis, thus contributing to better planning and evaluation of waste management policies.

- The incorporation of variables with missing data in econometric models has shown that, although it reduces the total number of observations available, it increases the explanatory power and statistical relevance of the results. This is because the resulting subpopulations have a lower unexplained dispersion and a greater homogeneity in the behavior of the variables analysed. In addition, it is possible that there is a positive correlation between the municipalities for which more information is available and a better performance between the independent variables and the collection. In any case, it would be advisable to delve into these causes since they can provide valuable information on waste collection.

- In this sense, the improvement in the availability of data will allow the effects of the variables over time to be analysed more rigorously, which is seen to be important given the results of the variables for which there is data.

- A noteworthy element in all models is the low percentage of waste collection per capita explained by the independent variables used. This could be due to the omission of relevant variables, especially some related to waste management policies, both at municipal and supra-municipal levels, which are not included in the analyses. These policies can play a significant role in the effectiveness and results of kitchen waste and bio-waste collection per capita. Including these variables in future studies could improve the fitness of the models and provide a more accurate understanding of the determinants.

- The municipal-level data used in the analyses for Italy and Catalonia showed significant variability, something that became evident when a more exhaustive debugging of the analyses was carried out. This filtration involved removing municipalities that deviate too much from the average values of the sample studied. This filtration significantly improved the explanatory power and robustness of the econometric models. This suggests that it could be very useful to carry out additional analyses by grouping municipalities into clusters based on key variables such as population, the year of start of waste management, or the level of collection per capita. In this context, the determinants of collection could behave differently in municipalities that make greater efforts in waste management, which could provide valuable information on more effective policies.

- This study examined how socio-economic and waste management factors influence the per capita quantity of collected kitchen waste. Future research could delve into the performance of municipalities regarding kitchen waste quality, particularly by evaluating factors such as the presence of impurities.

Regarding the technical management takeaways from the statistical analysis, the main conclusions include:

- Collection model - DtD: When selecting the collection model, the demonstrated positive impact and good results of individualized models should be considered. DtD models allow for a greater capture of kitchen waste due to their convenience and ease in promoting a rapid and consolidated change of habits. This is especially clear in small and medium municipalities, but also applicable to large municipalities if the system is properly adapted to high density areas with multiapartment buildings. Successful individualized models and DtD schemes include continuous monitoring and education services.

- Population and population density: Collection per capita increases with the population and population density because it is easier to implement optimized and homogeneous collection systems with respect to rural areas with low and dispersed populations. Large or commercial producers, more present in urban and density areas, can also contribute to the collection rate if they are included in the system. This scenario should be accompanied by proper and individual collection models to efficiently capture the bio-waste generated, since other systems in densely populated areas do not demonstrate the same positive results. Specific solutions and measures to minimize the impact of contextual factors unique to disperse population and isolated producers should be incorporated when designing the collection models. This helps optimize logistics and capture rates, as does monitored home compositing (to treat in situ the organic flows). Zones with high density, as mentioned in the previous point, require the adaptation of individualized models, especially for the most complex case of multiapartment buildings.

- Tourism: Bio-waste generation per capita is typically high in touristic areas because it includes the quantities generated by touristic establishments and visitors (but the indicator is commonly calculated based on residents). The context and dynamics of tourist areas may not have a negative effect, if individual and more efficient collection models are implemented. In any case when designing the model, the complexity of these contexts should be considered together with the specific needs of large producers and the impact of the seasonal fluctuations.

- Other factors: Other socio-economic contextual factors, like social inequality, low level of education and higher unemployment may be associated with lower collection per capita, since the users are generally focused on other domestic problems that condition the willingness to participate in the collection system. In these cases, individualized models, paired with comprehensive communication actions and continuous monitoring services, can work as a positive solution to promote participation and increase capture rates. In addition, looking at the long historical track of Italian cases, collection per capita increases over time even in these complex areas, showing that some intrinsic nudging effect (the social norm that neighboring best practices can encourage others to do the same) slowly but steadily takes place.

- Frontrunners: The competent local authorities' commitment and political will is crucial, as this report concluded, especially in those contexts where frontrunners are not surrounded by other municipalities with similar management or there is unfavorable context with low landfilling costs and weak governance scheme in the area. Local entities that start bio-waste management at a later stage, on the contrary, have more reference points, which are important when designing the system and solving managerial problems. The willingness and commitment of early frontrunners is an impacting factor of success and should be considered when planning strategies in European regions that are far from achieving effective models and good results. This focuses on the role of local and regional frontrunners as a beacon of good practices and important reference for others.

- For more information on these technical management proposals, see **LIFE BIOBEST D3.1** **Guideline on separate collection**, **LIFE BIOBEST D3.2** **Guideline on governance and economic incentives**, **LIFE BIOBEST D3.4** **Factsheets on the analysis of best practices in communication and engagement from various countries** and **LIFE BIOBEST D2.3** **Assessment Matrix of Best Practices**.

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