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Research Paper

Socioeconomic factors explaining municipal solid waste generation in Galicia. Similarities and differences between aggregate magnitudes and fractions

Óscar Páramo-Telle *, Xavier Vence

University of Santiago de Compostela, ICEDE Research Group, Department of Applied Economics, Faculty of Economics and Business Sciences, Av. Do Burgo s/n, 15782 Santiago de Compostela, Galicia, Spain

A B S T R A C T

The rapid increase in Municipal Solid Waste (MSW) generation is a critical problem associated with economic development. Identifying the factors involved in MSW generation are key to designing strategies for responsible management and reduction. This study seeks to identify the factors involved in MSW generation and composition in Galicia (Spain). Multiple Linear Regression (MLR) analysis was used to study whether MSW generation was explained by increased disposable income per capita or other factors such as improved salaries, household consumption levels, improved Human Development Index (HDI) levels or an aging population. The models obtained add some interesting nuances to the existing literature. They present coefficients of determination (R^2) higher than 0.77 for total MSW and all fractions, surpassing tests of linearity, homoscedasticity, normality of residuals and independence of variables. The results also add some important details to the existing literature, suggesting that MSW generation is linked more to economic growth than to consumption. The aging Galician population did not correlate with MSW reduction, but improved HDI correlated with a reduction in mixed urban waste.

1. Introduction

One of the critical challenges associated with global economic and social development over the last century has been the accelerated increase in waste generation, especially Municipal Solid Waste (MSW) (Jing & Hipel, 2016). In pre-industrial societies and during the early stages of industrialization, waste generation was modest and often reused within both rural and urban spheres. However, the sharp rise in consumption rates over recent decades has turned waste into a serious economic and environmental challenge, requiring increasingly complex and costly management systems. A more sustainable approach to waste planning and management is required, with particular emphasis on environmental questions (Costi et al., 2004). This process begins with reliable data and appropriate information channels to ensure integrated waste management strategies adapted to citizens' needs and regional characteristics (Guerrero et al., 2013).

The magnitude of the problem forces us to pay more attention to waste management but especially to prevention and reduction. Adequate measures must be adopted to prevent waste generation and control and evaluate progress. A circular economy approach that focuses on short cycles for prevention (Reducing, Reusing, Repairing, Refurbishing, Remanufacturing, etc) is the most efficient way to improve resource use efficiency and reduce the environmental impact of waste (Stahel, 2010; Potting et al.,2017; European Parliament, 2018).

MSW is generated throughout various economic activities and stages, mainly during the sales and consumption phases, with domestic consumption being a prominent contributor. This lends great relevance to studying the factors that explain increases in MSW. The lack of consistent data in less developed areas has given impulse to considerable research efforts to estimate MSW (Alzamora et al., 2022), employing models as varied as the areas of study (Beigl et al., 2008). Some attempt to address the data gap by predicting MSW (Abbasi & Hanandeh, 2016; Kannangara et al., 2018), while others focus on identifying key factors behind the generation of specific types and quantities of MSW in different societies (Grazhdani, 2016; Vieira & Matheus, 2018; Namlis & Komilis, 2019).

In the existing literature, the factors influencing MSW generation are closely linked to models and levels of economic development, showing a relevant geographical diversity (Medina, 1997; Lebersorger & Beigl, 2011). Therefore, the main drivers must be studied for specific regions, to develop policies that address the specific conditions of those places. This highlights the importance of gaining a deeper understanding of the factors driving MSW generation to effectively reduce waste and improve its management.

* Corresponding author.
E-mail addresses: oscar.paramo.telle@usc.es (Ó. Páramo-Telle), xavier.vence@usc.es (X. Vence).

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In order to contribute to a deeper understanding of the factors driving MSW generation this paper examines the Galician case, an autonomous Spanish territory with specific economic characteristics and with its own government and policies, including those related to waste management. The main reasons to deal with this case are twofold. First, this region has experienced considerable socioeconomic changes in recent decades including the rapid decline of the primary sector, more accelerated rural depopulation (with corresponding changes in consumption and waste generation patterns), rising per capita income, and a prolonged period of demographic stagnation combined with an aging population (Vence, 2009; López Iglesias, 2016).

Second, MSW in Galicia has steadily increased in the last two decades, accounting for 28.67 % of total waste in 2018 (Consellería de Medio and Ambiente, 2021; IGE, 2023a). In addition, 94 % of Galician municipalities rely on a relatively outdated MSW management system based mainly on incineration and very little recycling. In fact, Galicia accounted for 5.68 % of Spain's population in 2021, but only 3.7 % of the country's recycled waste and 22.7 % of incinerated waste (MITECO, 2021).

Thus, the main question is how have socioeconomic and lifestyle changes affected MSW generation? This study seeks to identify the main socioeconomic drivers of MSW generation in Galicia during the first two decades of the twenty-first century (2004–2021), focusing on total MSW and specific fractions. The research aim is to determine the main drivers of MSW generation by assessing economic growth measured in GDP per capita, purchasing power measured by salaries and wages, household consumption patterns or regional sociodemographic dimensions such as population aging and improved scores on the Human Development Index (HDI).

The remainder of the paper is organized as follows. Section 2 reviews the existing literature on MSW predictive models and determining factors. Section 3 describes the data sources and the methodology used, and Section 4 presents the results of the developed models. Section 5 discusses the findings for Galicia, comparing and contrasting them with other research, and Section 6 provides the main conclusions.

2. Literature review

Globally, the amount of MSW has been increasing rapidly for decades and its composition is increasingly complex (Vergara & Tchobanoglous, 2012). From 1990 to 2020, MSW generation increased by 33.41 % in OECD countries (OECD, 2024). With economic and demographic growth, MSW is projected to increase by 56 % from 2020 to 2050, generating some 3.8 billion tons globally (UNEP & ISWA, 2024). Environmentally, this presents a growing economic and waste management problem of great concern. Waste policies in developed countries are evolving to address this reality. The EU Waste Framework Directive, for example, contains a hierarchical concept of waste management consisting of five steps: prevention, reuse, recycling, recovery and disposal (European Parliament & Council of the European Union, 2008). In 2015, the first Circular Economy Action Plan became a central element of the Waste Framework (European Commission, 2015; Alenza García, 2021). It seeks to address multiple challenges, since generated waste must be reduced, sustainably managed, reused and recycled to take advantage of its value and reduce associated environmental and social impacts (European Commission, 2015; Santamaría Arinas, 2022).

2.1. Overview of literature reviews

Several empirical and theoretical studies have been developed to identify key factors in waste generation and determine which should be prioritized to ensure waste reduction. These studies vary in regional scale, methodology, waste flows, types of data, and independent variables analyzed (Beigl et al., 2008; Cherian & Jacob, 2012; Grazhdani, 2016; Kolekar et al., 2016; Alzamora et al., 2022; Šomplák, et al., 2023).

Beigl et al. (2008) classified 45 MSW generation models that were published from 1974 to 2005 based on regional scale, waste flows modelled, independent variables, modelling methods and duration of the series analyzed. Cherian & Jacob (2012) did a similar grouping of 9 articles to examine socioeconomic factors that might help identify statistical modelling options. Kolekar et al. (2016) contributed to the model reviews by including 20 new articles published between 2006 and 2014. Other reviews attempted to pinpoint socioeconomic factors affecting MSW generation (Alzamora et al., 2022) and management (Ma & Hipel, 2016). Goel et al. (2017) focused on models to prevent MSW generation, while other studies reviewed models directly by applying artificial intelligence to MSW management (Abdallah, et al., 2020), using artificial neural networks (Xu et al., 2021) or machine learning methods to predict recycling processes and treatment (Guo et al., 2021). More recently, Šomplák, et al. (2023) reviewed articles published in prior literature reviews and widened the sample by classifying 360 articles, building upon the methodologies of Beigl et al. (2008) and Kolekar et al. (2016).

2.2. Geographic scale, modelling methods, and MSW streams

There are two main approaches to examining the geographic area under study. Some are micro-level studies that obtain data mainly through questionnaires to predict domestic MSW generation, characteristics, and socio-economic drivers (Ojeda-Benítez et al., 2008; Gómez et al., 2009; Thanh et al., 2010; Khan et al., 2016; Villalba et al., 2020). Other studies focus on broader areas, from combining questionnaires with area statistics in settled areas with homogeneous home features (Beigl et al., 2008) to studies of municipalities (Sharholy et al., 2007; Abbasi & Hanandeh, 2016), regions (Chung, 2010) or countries (Liu & Wu, 2010). In studies at country level, data on total annual waste generated is collated with economic and census data from statistics departments (Keser et al., 2012). Accordingly, total MSW generated is the most commonly reported metric (He et al., 2022).

Selection of specific and appropriate methodology depends mainly on the nature of the input data and the model objectives (Šomplák, et al., 2023). Most methods are based on correlation and regression analyses, time series, or group comparisons. More advanced approaches, such as input–output modelling, system dynamics, and artificial intelligence, have also been utilized. However, the numerous and complex interactions among variables present significant challenges for validation (Kolekar et al., 2016).

For the dependent variable to be predicted, most of the literature contains models for predicting total MSW volume (Alzamora et al., 2022; Šomplák, et al., 2023). However, some studies use waste fractions such as organic matter, glass, paper and cardboard or plastic and metal packaging (Thanh et al., 2010; Oribe-García, et al., 2015; Prades et al., 2015; Ayeleru et al., 2018), while others study mixed or selective subtotals along with individual fractions (Kannangara et al., 2018; Nguyen et al. 2020).

2.3. Key socioeconomic factors influencing MSW generation

This paper presents a thorough analysis of factors affecting MSW generation in Galicia, drawing on reference variables commonly used in the literature to characterize household consumption levels and patterns.

2.3.1. Population

Total population appears as a key parameter frequently employed in MSW prediction models when absolute values are involved (Liu & Yu, 2007; Chung, 2010; Abdoli et al., 2011; Chen et al., 2012; Kannangara et al., 2018). However, most studies emphasize the intensity of waste generated per individual, using MSW per capita as a variable of interest (Hockett et al., 1995; Dennison et al., 1996; Chung, 2010; Lebersorger & Beigl, 2011).

2.3.2. Age structure

An important factor affecting consumption and waste generation patterns is age and therefore population aging must be taken into account (Lindh, 2003). This is a suitable variable for forecasting as it captures medium-term trends and varies slowly, thereby increasing prediction accuracy (Kannangara et al., 2018). Age structure is cited as one of the most relevant factors affecting per-capita MSW generation (Chung, 2010). In fact, the adult population aged 15 to 59 (Beigl et al., 2008; Ghinea et al., 2016) or 18 to 49 (Jekins, 1993) has been found to influence waste generation significantly, indicating that aging societies tend to generate less waste (Kannangara et al., 2018; He et al., 2022; Hondroyiannis et al., 2024). However, other studies did not find the age variable to be significant (Mazzanti & Zoboli, 2008; Lebersorger & Beigl, 2011).

2.3.3. Gross domestic Product

Because the volume of waste generated is strongly linked to economic growth (Gardiner & Hajek, 2020), Gross Domestic Product (GDP) is the most commonly used explanatory variable in the literature (Thøgersen, 1996; Keser et al., 2012; Antanasijević et al., 2013; Wei et al., 2013). A positive linear correlation was observed between MSW generation and GDP (Liu & Yu, 2007; Shekdar, 2009; Thanh et al., 2010; He et al., 2022) or GDP per capita (Chung, 2010; Giannakitsidou et al., 2016; Akther et al., 2025). Namlis and Komilis (2019) found that GDP was a significant predictor for the generation rates of 9 waste streams.

2.3.4. Household income

Household income is another widely recognized factor affecting MSW generation (Kolekar et al., 2016; Grazhdani, 2016). Several authors have found that income is positively related to household waste generation rates (Medina, 1997; Escarimosa et al., 2001; Ojeda-Benítez et al., 2008; Ogwueleka, 2013; Zia et al., 2017). However, Thanh et al. (2010) only found a positive correlation with the rate of food waste generation. More accurate income data is needed to develop a more reliable prediction of MSW generation (Abdoli et al., 2012).

2.3.5. Household consumption

It seems quite reasonable to assume that consumptions pattern directly influence both the amount and composition of MSW generated (Purcell & Magette, 2009; Ogwueleka, 2013). Consumption-related variables illustrate the link between living conditions and waste generation patterns (Beigl et al., 2008). Regression analyses using consumption as an independent variable reveal it to be a main explanatory factor in MSW generation (Wei et al., 2013; Grazhdani, 2015; Ghinea et al., 2016), due to increased average consumption in the population and the excessive consumption behaviors of populations with more resources (Dai et al., 2011; He et al., 2022).

2.3.6. The Human Development Index

The Human Development Index has recently appeared as another factor in the relevant literature (Giannakitsidou et al. 2016; Vieira & Matheus, 2018; Namlis & Komilis, 2019). This index summarizes average achievement in key dimensions of human development: a long and healthy life, being knowledgeable and having a decent standard of living (United Nations Development Programme (UNPD), 1990). Its multidimensionality may also help explain waste generation and household behavior. Vieira and Matheus (2018) studied the correlation between MSW generation and HDI, while Giannakitsidou et al. (2016) and Namlis and Komilis (2019) developed regression models that showed a direct influence of HDI on MSW generation.

3. Data and methodology

3.1. Dependent variables: MSW generated in Galicia

Galicia has two waste management models. The dominant one, implemented by the regional government of Galicia, covers 94 % of the Galician municipalities (294) and uses a system that separates waste into 4 fractions: Light Packaging (LPA), Paper-Cardboard (P&C), Glass (GLA) and "Remainder", which includes mixed and organic waste. The minority model, covering the remaining 6 % of the municipalities, is based on a 4-fraction wet/dry model that separates waste into Inorganic, Organic, P&C and GLA. Therefore, across Galicia, we divided the Total MSW Generated (TOT) into two large subtotals: The Mixed Subtotal (MIX), comprising the Remainder and Inorganic Fractions; and the Selective Subtotal (SEP) of the Organic, GLA, P&C and LPA fractions (IGE, 2017).

Waste data are often incomplete and sometimes unreliable (Giusti, 2009). Government reports are usually the only source for such information, which makes them difficult to verify (Kawai & Tasaki, 2016). In Galician statistics, the amount of municipal waste generated and collected appears as a single variable which does not include quantities generated and not collected but deposited illegally in unauthorized points. Additionally, in the data provided by the Galician Institute of Statistics (IGE) until 2015, the TOT did not coincide with the sum of the SEP and MIX subtotals, since only the majority fractions were reflected. Bulky Waste (BW), Batteries and Waste Electrical and Electronic Equipment (WEEE) were excluded. Therefore, to standardize the SEP fraction, the amount corresponding to the minority fractions collected selectively during the 2004–2015 period was added to this subtotal.

MSW total and fractional generation data in Galicia are expressed in total tons per year (IGE, 2023a). Waste generation data in tons of each fraction (i) in each year (j), were normalized by the number of inhabitants of Galicia for the corresponding year (j) (IGE, 2023b) and converted into kg per inhabitant per year.

3.2. Independent variables

Based on variables previously used in the literature, we selected the following five independent variables:

1. GDP per capita at Constant Prices (GDP pc):

Galician GDP values at Market Prices in thousands of euros (IGE, 2023c) were deflated to account for the Consumer Price Index (CPI) (IGE, 2023d) and related to the population (IGE, 2023b) to obtain the GDP pc at constant prices for 2021, measured in euros per inhabitant.

2. Household Final Consumption per capita at Constant Prices (HFC pc):

Household Final Consumption in thousands of euros (IGE, 2023c) was deflated to account for the CPI (IGE, 2023d) and related to the population (IGE, 2023b) to obtain the HFC pc in euros per inhabitant for 2021.

3. Average Wages and Salaries at Constant Prices (W&S):

Statistics referring to Salaries and Wages in thousands of euros (IGE, 2023c) were deflated to account for the CPI (IGE, 2023d) and related to the average annual number of Workers affiliated in the Social Security System (SEPE, 2023) to obtain the W&S in euros per affiliate.

4. Human Development Index (HDI):

According to the United Nations Development Programme (UNPD), 1990, the Human Development Index (HDI) is a geometric average of three normalized indices that measure key dimensions of human development: health and longevity, education, and standard of living.

- The health dimension is assessed through life expectancy at birth.

- The education dimension is measured by the mean years of schooling for adults aged 25 and older and the expected years of schooling for children entering school.
- The standard of living dimension is evaluated using gross national income (GNI) per capita. To account for the diminishing marginal utility of income, the HDI applies the logarithm of GNI.

The scores of these three HDI dimension indices are then combined into a composite index using a geometric mean. HDI information for Galicia was obtained from the Radboud University Institute for Management Research, Radboud University (2023).

5. Aging Index (AI):

Given the lack of common criteria for selecting a specific age group as an independent variable, correlations between MSW generation and various age group combinations were calculated. Finally, we decided to use the Aging Index (AI), which combines the evolution of the two extreme brackets. It measures the relationship between the population over 64 and the population under 20 years of age (IGE, 2023b) using the following equation:

$$\text{Aging Index} = \frac{\text{Population over 64 years of age}}{\text{Population under 20 years of age}} \text{ x } 100$$

3.3. Multiple linear regression (MLR) analysis

With the variables indicated in the previous section, we conducted a multiple linear regression analysis to determine which factors had the greatest influence on total and fractional MSW generation, establishing comparisons over time using aggregate variables. This coincides with the methodology used most in the literature (Beigl et al., 2008; Alzamora et al., 2022). Quantitative relationships between the variables were determined with the following equation:

$$\text{Yi} = b_o + b_1X_1 + b_2X_2 + b_3X_3 + \cdots + b_nX_n + \varepsilon \quad (1)$$

where Y_i is the dependent variable; b_o is the constant term; X_1, X_2, X_3, X_n are the independent variables; B_1, B_2, B_3, B_n are the regression coefficients of their respective independent variables; and ε is the residual error that is assumed to be independent and identically distributed with zero mean and constant variance. The value of the regression coefficients can be positive or negative, indicating a direct or inverse relationship of the independent variable with the dependent variable, respectively.

Using the independent variables selected above, all possible regressions were performed for each dependent variable, considering different combinations of independent variables. The total number of regression models for each of the dependent variables was 2^{k-1}, where k is the number of independent variables selected. From the resulting 31 models for each of the dependent variables, the model that minimized the Bayesian Information Criterion (BIC) was selected. Because of the potential correlation among variables, the Variance Inflation Factor (VIF) was calculated for each explanatory variable in every model, as described by Belsley et al. (1980). If the values of any variables exceeded 4 (Miles & Shevlin, 2001), the model was adjusted by removing one variable to maximize the BIC. This process was repeated until multicollinearity was adequately resolved.

Each model was tested for linearity (Ramsey Test and Harvey-Collier Test), homoscedasticity (Harrison-McCabe Test and Breusch-Pagan Test), residuals normality (Shapiro Test for residuals and for standardized residuals) and independence of the variables (Durbin Watson Test and Breusch-Godfrey Test). Each test was performed according to the methodology described in Krämer & Sonnberger (1986).

For the BW and WEEE fractions, data were only available for 6 years. A two-variable regression model was selected that met most of the verification criteria.

4. Results

4.1. Descriptive statistics

Before presenting the results of these models, a brief description is provided of the evolution of the independent variables and total MSW generation (Graph 1), as well as the dependent variables (Graph 2) for the 2004–2021 period.

First, the evolution of total waste generation appears to be aligned with economic cycles (Graph 1). MSW generation expanded in periods of economic growth or recovery (2004–08 and 2013–19) and contracted with the 2008 crisis, the subsequent Great Recession and the Covid-19 pandemic, to which the reduction of economic, industrial, and consumer activities has been attributed (Olawade, et al., 2024).

For socioeconomic indicators (Graph 1), the non-cyclical evolution of the HDI is worth highlighting, as its positive progress only slowed during the Covid-19 pandemic. The Aging Index has also increased at a marked and relatively constant rate since the beginning of the series, reflecting the persistent, long-term aging trend of the Galician population.

Despite the general pairing of almost all MSW generation and fractions with socioeconomic indicators, increased plastic packaging waste during the Covid-19 pandemic stands out, probably reflecting increased online shopping and its corresponding packaging (Leal et al., 2021). The descriptive statistics of the variables used in the Multiple Linear Regression Analysis are shown in Table 1.

4.2. Regression equations for waste generation and socioeconomic indices

Once the models had been screened, eight models were selected: one for total MSW generated, two for the mixed and selective subtotals and five for the various selectively collected waste fractions. All the regression models obtained, with all the significant variables that minimize the BIC, explained between 77.25 % and 97.83 % of each type of MSW generation. The results are shown in Table 2.

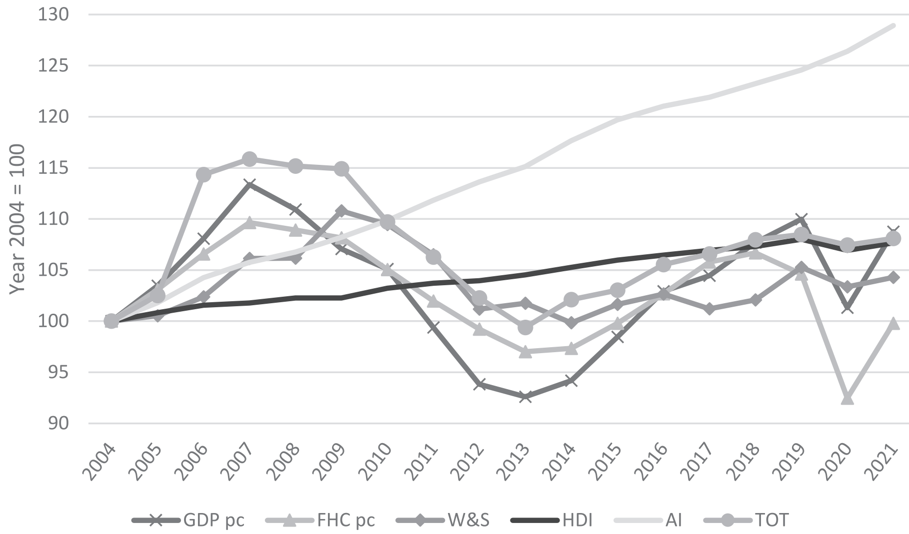
The TOT explanatory model showed direct relationships of GDP pc evolution and average W&S with MSW generation. W&S exerted a stronger influence on MSW generation.

Using the Harrison-McCabe, Breusch-Pagan and Shapiro tests of residuals and standardized residuals, we confirmed the hypotheses of homoscedasticity and normality of residuals in all models except MIX, which did not pass the Breusch-Pagan test. The Ramsey test for linearity contrasted the null hypothesis for all the models obtained except for the BW generation model, while the Harvey-Colley test did not support the linearity hypothesis in the explanatory model for MIX generation. Finally, the Breusch-Godfrey test confirmed the independence of residuals for all fractions, as did the Durbin-Watson test, with the sole exception of the LPA fraction.

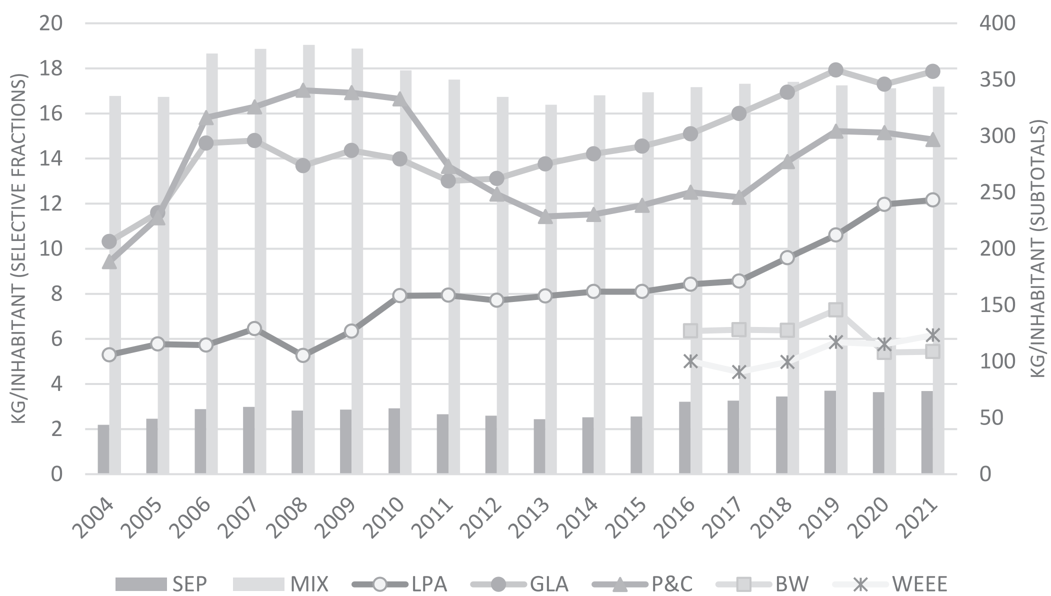
A synthesis of the results shows that: a) GDP pc was identified as a significant independent variable that increases the generation of total MSW, its subtotals, and the LPA, GLA and P&C majority fractions. b) W&S was directly related to the generation of total MSW, the MIX subtotal, and the LPA, P&C and WEEE fractions; c) HFC was negatively related to LPA generation; d) HDI was negatively related to MIX generation but positively related to BW generation; e) AI directly influenced generation of the SEP subtotal and all specific fractions except P&C.

5. Discussion

There is substantial debate in the literature regarding the factors that determine MSW generation. Most research has found evidence of a positive linear correlation between MSW generation and GDP pc, for total MSW (Giusti L., 2009; Chung, 2010; Giannakitsidou et al., 2016; Pisani Junior et al., 2018; He, et al., 2022) and most MSW fractions (Namlis & Komilis, 2019). Our results align with the literature, but they allow us to identify some important details. We found a clear and



Graph 1. Total waste generation and independent variables used in the multiple linear regression analysis, Galicia 2004–2021 (Year 2004 = 100) .
Source: author's own based on IGE (2023c, 2023d, 2023e) and data from the Radboud University Institute for Management Research (2023)



Graph 2. MSW generated and collected per inhabitant in Galicia, subtotals and selective fractions 2004–2021 (Kg/inhabitant) .
Source: Author's own based on IGE (2023a, 2023b)

Table 1
Descriptive statistics of the variables used in the Multiple Linear Regression Analysis.

Variable	Code	Mean	SD	Min.	Max.	Variation 2004–2021
Total waste generated (KG/inhabitant)	TOT	414.10	20.20	383.92	447.54	8.09 %
Separated waste generated (KG/inhabitant)	SEP	58.74	9.27	43.80	74.07	68.50 %
Mixed waste generated (KG/inhabitant)	MIX	349.65	16.70	327.80	380.81	2.45 %
Light Packaging waste generated (KG/inhabitant)	LPA	7.99	2.07	5.26	12.16	129.85 %
Glass waste generated (KG/inhabitant)	GLA	14.62	2.04	10.31	17.92	73.24 %
Paper-cardboard waste generated of (KG/inhabitant)	P&C	13.80	2.28	9.42	17.03	57.55 %
Bulky waste generated (KG/inhabitant)	BW*	6.21	0.71	5.39	7.29	−14.38 %
Waste Electrical and Electronic Equipment generated (KG/inhabitant)	WEEE*	5.38	0.63	4.53	6.17	22.96 %
Gross Domestic Product per capita at 2021 Constant Prices (€/inhabitant)	GDP pc	22,909.25	1,354.4	20,514.16	25,111.93	8.74 %
Final Household Consumption at 2021 Constant prices (€/inhabitant)	FHC pc	14,199.14	643.98	12,784.47	15,157.94	−0.20 %
Average Wages and Salaries (€/contributor)	W&S	22,322.83	682.90	21,506.54	23,864.39	4.29 %
Human Development Index	HDI	87.26	2.13	83.6	90.3	7.66 %
Aging Index	AI	145.28	11.29	126.9	163.6	28.92 %

[a] Note: The fractions marked with * only include data from 2016 to 2021.
Source: Author's own based onIGE (2023a, 2023b, 2023c, 2023d, 2023e) & Radboud University Institute for Management Research (2023).[a]

Table 2
Explanatory models and verification contrasts for the generation of total MSW, subtotals and fractions (that minimize the BIC). Galicia, 2004–2021.

	TOT	SEP	MIX	LPA	GLA	P&C	BW	WEEE
Coefficients								
Intercept	−55.007045	−59.886589***	193.545967	−11.122379 ·	−24.16439***	−47.845384***	−88.821269*	-33.902608**
GDP pc	0.009592***	0.003511***	0.00653**	0.000530**	0.000695***	0.000674*		
W&S	0.011171**		0.009476*	0.000424***		0.00207***		0.001141*
HFC				−0.001623 ·				
HDI			−2.34973*				1.436372*	
AI		0.302204***		0.1411575***	0.157260***		−0.213671**	0.08837*
Variance Inflation Factor								
GDP pc	1.3612	1.0039	1.362035	2.9525	1.0039	1.3612		
W&S	1.3612		1.379165	1.4074		1.3612		
HFC				3.3782				
HDI			1.014816				1.4911	1.6514
AI		1.0039		1.3999	1.0039		1.4911	1.6514
Coefficient of determination								
R^2	0.8063	0.7967	0.7725	0.9499	0.917	0.7972	0.9455	0.9783
R^2 adjusted	0.7805	0.7696	0.7237	0.9345	0.9059	0.7702	0.9091	0.9639
Verification contrasts (p-value)								
Ramsey	0.605	0.696	0.139	0.717	0.233	0.473	0.044	0.756
Harvey-Collier	0.932	0.472	0.021	0.316	0.662	0.093	0.443	0.866
Harrison-McCabe	0.913	0.706	0.899	0.748	0.826	0.916	0.729	0.705
Breusch-Pagan	0.213	0.628	0.04	0.704	0.27	0.331	0.165	0.288
Shapiro	0.472	0.866	0.621	0.213	0.593	0.572	0.607	0.607
Shapiro residuals standard	0.411	0.876	0.604	0.327	0.693	0.63	0.714	0.939
Durbin- Watson	0.275	0.0563	0.1	0.003	0.124	0.249	0.197	0.499
Breusch-Godfrey	0.812	0.582	0.926	0.146	0.8	0.699	0.468	0.308

Note: significance codes for the p-values of the estimated coefficients: ≤ 0.001 '***'; ≤ 0.01 '**'; ≤ 0.05 '*'; ≤ 0.1 '·'.

positive relationship between increased GDP pc and increased generation of total MSW and five of the seven MSW fractions (SEP, MIX, LPA, GLA, and P&C). However, GDP pc did not explain BW and WEEE.

As indicated earlier, some studies eliminate the GDP pc variable in regressions due to the presence of multicollinearity. Keser et al. (2012) and Younes et al. (2015) discarded GDP pc in favor of age-stratified population groups in their models. Their model separated the total number of people in the sample into age groups, thus omitting the influence of the age-range percentage structure, to analyze the influence of the evolution of population fractions. While those authors concluded that the over-65 population drastically influenced solid waste generation, the influence of age on MSW generation remains controversial. Some studies do not find the age variable significant (Mazzanti & Zoboli, 2008; Lebersorger & Beigl, 2011) while others report that the adult age group generates the most MSW (Jekins, 1993; Beigl et al., 2008; Ghinea et al. 2016) and aging population exert less pressure on MSW generation (Hondroyiannis et al., 2024). Our study results based on the Aging Index also point to a significant and positive influence, indicating that aging did not reduce MSW generation, except for the BW fraction. This may be due to a greater propensity to properly maintain and use old furniture and fixtures (possibly good quality and durable) or repair them and prolong their useful life. More detailed studies are needed to identify whether there is an age-related pattern of waste generation or if other explanatory factors related to the social dynamics of each territory are involved, such as increased waste collection coverage.

Several studies recognize economic status as the main driver of MSW generation (Hocket et al., 1995; Sujauddin et al., 2008; Vieira & Matheus, 2018) and composition (Sudhira et al., 1998; Hidalgo et al., 2019). Some directly relate household income to MSW generation (Medina, 1997; Escarimosa et al., 2001; Ojeda-Benítez et al., 2008; Ogwueleka, 2013; Zia et al., 2017), with the highest-earning families tending to generate the most MSW (Sujauddin et al., 2008). Our results are similar to those of Liu and Wu (2010), indicating that W&S is more closely related to total MSW generation than GDP pc.

Rather unexpectedly, consumption was not an explanatory variable for MSW evolution; however, it did turn out to be a predictor of the amount of packaging waste. Consequently, in Galicia we cannot support the claim that consumption positively impacts waste generation (Liu & Wu, 2010; Wei et al., 2013; Grazhdani, 2015; Ghinea et al., 2016). Contrary to expectations, consumption turned out to be a negative predictor of packaging waste generation. Although high levels of overall consumption and waste drive MSW generation (Dai et al., 2011; He et al., 2022), these results seem to suggest that other factors are involved. One hypothesis could be that the composition of consumption changes as it increases (for example, greater consumption of services). Alternatively, low elasticity in the demand for packaged basic necessities may mean that increased household consumption would be accompanied by decreased MSW packaging per capita.

The inverse relationship between the HDI and mixed-waste generation in Galicia indicates that it diminished as the level of development increased and the implementation of waste separation progressed. This may align with previous results that have found a direct influence of the HDI on urban waste generation from plastics, construction and demolition, and Pb-acid batteries (Namlis & Komilis, 2019). Similarly, Giannakitsidou et al. (2016) observed a direct relationship between the HDI, total MSW generated, and waste destined for composting, incineration or recycling. They also reported an inverse relationship with waste destined for landfill, similar to what occurred with the mixed fraction in Galicia. These results may also reflect the positive impact of education on waste separation for collection, to the detriment of mixed collection (Alzamora et al., 2022).

The relatively discordant results for some fractions may reflect (modest) efforts to increase selective collection of waste fractions by progressively – though unevenly and at different rates – installing containers for selective collection of Glass, Packaging and Paper-Cardboard. The results for WEEE may also be highly affected by the incipient collection network for that fraction. Comparing these explanatory factors requires a fresh analytical perspective, with additional information on variables related to the evolution of waste management policies, collection coverage for each type of waste, or substituting one type of goods consumption with another (e.g., electronic for paper, paper for plastic, etc.).

6. Conclusions

This research deals with the main drivers of MSW generation in Galicia, in terms of total generation and main fractions, focusing mainly on socioeconomic factors.

We conclude that MSW generation is an inherent feature of economic growth, measured in terms of GDP pc, as indicated by the clear coupling of both variables. GDP pc acts as a robust predictor of total MSW and most fractions. However, we found that MSW generation was impacted more by wages and salaries than GDP pc.

In fact, a 1 % increase in annual GDP per capita leads to a 0.52 % rise in total annual MSW generation, while a 1 % increase in wages and salaries results in a 0.61 % increase. Similarly, a 1 % increase in GDP per capita leads to a 0.41 % rise in mixed MSW generation, whereas a 1 % increase in wages and salaries results in a 0.67 % increase. This is a relevant policy result and confirms that habits acquired with greater purchasing power tend to increase MSW generation, especially the mixed waste, despite the eventual increase in the relative share of services in household consumption.

Other socioeconomic factors are also relevant, particularly in explaining the evolution of specific MSW fractions. To integrate both the social and demographic dimensions, we examined the influence of improved HDI scores and the aging population in Galicia. Although clear conclusions could not be drawn for most of the fractions, the results suggest that increased HDI corresponded to a reduction in the mixed subtotal. This could indicate that improvements in the waste collection network and progress in health and education have translated into reduced generation of mixed waste in favor of selected fractions, which facilitates recycling. In contrast, population aging in Galicia did not contribute to reducing waste generation, except for bulky waste, but was a relevant factor in MSW generation. Uncovering the causes of this relationship requires more specific studies to compare waste generation patterns between older and younger populations and identify any associative trends for the variables.

The findings of this study provide valuable insights for developing targeted waste management policies in Galicia and similar regions. The strong correlation between economic indicators, such as wages and GDP per capita, and MSW generation underscores the need for strategies that address consumption patterns associated with rising income levels. In fact, a €1,000 increase in wages and salaries results in an 11.17 kg increase in total MSW generation, of which 9.48 kg correspond to the mixed subtotal. This finding could serve as a basis for the design of progressive local MSW taxes in accordance with the new European regulation currently being implemented (European Parliament, 2018). Policymakers could prioritize waste prevention initiatives, including public awareness campaigns focused on sustainable consumption and incentives to minimize waste generation at the source. Given Galicia's aging population, such campaigns should address older age groups specifically, as this demographic was not associated with reduced waste generation. Moreover, the relationship observed between improved HDI scores and decreased mixed waste generation highlights the significance of integrating educational programs and enhancing waste separation infrastructures to improve recycling rates. These findings may serve as a reference for designing adaptive waste management strategies that balance economic development with environmental sustainability, in Galicia and other regions with similar socio-economic and demographic characteristics.

One limitation of this study and the reference models is that they focus on factors that determine household waste generation and variables that reflect household economic and social characteristics, but do not include factors linked to waste collection and management processes. The evolution of collection networks, infrastructure, and equipment, especially for sorted waste, should be studied explicitly, emphasizing areas where generation and collection statistics are not differentiated.

A possible expansion of this work could involve a detailed study of predictive MSW models at the municipal level, with research design that accounts for economic disparities and socio-cultural diversity. This would allow local authorities responsible for collecting MSW to establish measures adapted to their territory.

CRediT authorship contribution statement

Óscar Páramo-Telle: Writing – review & editing, Writing – original draft, Software, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Xavier Vence:** Writing – review & editing, Visualization, Validation, Supervision, Investigation, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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