

Original Research Article

Evaluating Pay-as-You-Throw System Implementation for Urban Waste Management: Evidence from Guimarães, Portugal

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Cite as: Pereira, A., Cunha, J., Evaluating Pay-as-You-Throw System Implementation for Urban Waste Management: Evidence from Guimarães, Portugal, *J.sustain. dev. energy water environ. syst.*, 14(4), 1140731, 2026, DOI: <https://doi.org/10.13044/j.sdewes.d14.0731>

ABSTRACT

Rapid population growth, combined with increasingly consumption-oriented lifestyles and the intensification of economic activities, has led to a significant rise in natural resource use and municipal solid waste generation, posing major challenges to environmental sustainability. In response to these pressures, the circular economy has emerged as a strategic framework to decouple economic growth from resource consumption by promoting waste prevention, efficient resource use, and the recovery and regeneration of materials throughout their life cycles. This study presents the outcomes of a circular-economy-oriented waste management initiative: the implementation of a Pay-as-You-Throw system for municipal solid waste collection in the municipality of Guimarães, Portugal. The analysis assesses the system's effectiveness in reducing landfill disposal and encouraging households to separate waste and recycle. The results indicate that the Pay-as-You-Throw system has contributed to a measurable decrease in the volume of waste sent to landfills, alongside an improvement in recycling performance, thereby reducing environmental pollution and supporting the conservation of natural resources. Furthermore, the implementation of the system has generated economic benefits through more efficient waste management operations. It has produced positive social outcomes by fostering greater environmental awareness and behavioural change among residents. Overall, the findings demonstrate that Pay-as-You-Throw systems can serve as an effective policy instrument within a circular economy framework, contributing to the development of more sustainable urban systems and supporting broader environmental and resource efficiency objectives.

KEYWORDS

Sustainable development, Circular economy, Waste management, Pay-as-You-Throw, Case study, Guimarães.

INTRODUCTION

Contemporary society is increasingly defined by a consumer-oriented lifestyle, accompanied by heightened economic activity and a corresponding rise in waste generation and its associated challenges [1]. Waste refers to materials discarded because of perceived loss of utility or economic value [2]. It represents a significant environmental, social, and public health concern, necessitating the urgent adoption of innovative management strategies and sustainable alternatives [3].

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The Linear Economy Model emerged alongside the Industrial Revolution [4], a period distinguished by rapid technological and scientific advancements. These developments largely overlooked environmental constraints and the long-term externalities they generated. Within this model, natural resources are extracted from the environment and processed by organisations into goods and/or services, which are subsequently distributed for consumption. After use, these products are typically discarded, creating waste. The linear model is thus characterised by a production-consumption-disposal pattern, whereby consumers use products and subsequently discard them, contributing to the accumulation of substantial volumes of non-biodegradable waste in landfills [5]. However, [6] emphasised that the traditional perspective of waste as a material requiring immediate disposal has evolved significantly over recent decades. This shift is largely attributed to the development of the concept of integrated waste management, which promotes a more holistic approach. This framework involves coordinating waste collection, treatment, and, as a final step, disposal. The objective is to optimise environmental outcomes while simultaneously promoting the economic sustainability of waste management systems.

In contrast to the linear economy model, the circular economy model seeks to bridge the gap between resource extraction and waste generation by transforming waste materials into valuable inputs for the economy. It rejects the traditional ‘take-make-use-dispose’ paradigm [7] and instead promotes a regenerative system that aims to minimise resource flows. This approach emphasises strategies such as reduction, maintenance, repair, recycling, and reuse of products [8]. Rooted in the principles of sustainable development, the circular economy is guided by the imperative to meet present needs without compromising the ability of future generations to meet their own [9].

Waste Management Trends in Europe

The European Union’s waste management strategy, articulated in legislative instruments such as Directive 2018/851/EU of the European Parliament and the Council, establishes a hierarchical framework for waste management practices [10]. This hierarchy prioritises prevention, followed by reuse, recycling, other forms of recovery, and, as a last resort, landfill disposal. The objective is to promote the efficient use of natural resources and to mitigate the adverse environmental impacts associated with waste generation and disposal. The hierarchy seeks to maximise product lifespan and minimise waste volume, thereby encouraging the prioritisation of waste prevention, reuse, and recycling over landfill disposal. Landfilling is deemed the least desirable option due to its environmental impacts, including irreversible resource loss and potential long-term environmental liabilities.

In alignment with the EU’s Circular Economy Action Plan, recyclable materials are reintegrated into the economy as secondary raw materials, which can be traded and utilised in the same manner as primary raw materials [2]. This model shifts the focus from immediate disposal to the valorisation of waste, thereby reducing the quantity of discarded products. Nevertheless, secondary raw materials currently constitute only a limited proportion of the total materials consumed within the European Union economy [11].

The concept of the circular economy originated in industrial ecology as a response to the need for societal and industrial transformations aimed at achieving the sustainable and responsible use of natural resources [12]. It seeks to extend product life cycles and reintegrate used materials into production processes, thereby minimising waste generation and reducing environmental pollution [13].

In this context, the efficient management of municipal solid waste (MSW) [14] assumes particular importance. Traditionally, in the waste tariff system adopted by many municipalities, there is no direct link between the waste generated and the price charged for collection [15]. Therefore, there is no incentive for households and commercial businesses to reduce waste. However, as emphasised by [16], differentiated fee systems increasingly support waste reduction by allocating waste management costs in proportion to the amount of waste

generated. One waste management system implemented by several municipalities across different countries is the Pay-As-You-Throw (PAYT) system [10].

This study responds to the call by [10], who highlight the need for further empirical research to more clearly elucidate the effects of introducing a PAYT system. In fact, despite growing interest in such tariff schemes, there are still few concrete case studies documenting their impacts. To address this gap in the literature, this study seeks to answer the following research question: to what extent does the implementation of a PAYT system contribute to reducing landfill disposal and improving household waste separation and recycling in Guimarães, Portugal? The contribution of this study lies in presenting an empirical evaluation of a PAYT system implemented at the municipal level within a circular economy framework. Although prior research has examined PAYT schemes across a range of international contexts, empirical evidence from Southern European municipalities, particularly within Portugal, remains scarce. This study addresses this gap by providing context-specific insights into the environmental impacts of such a system, thereby advancing environmental sustainability in urban areas. Furthermore, given that source separation of waste is widely regarded as a key strategy for addressing the growing volume of urban waste and enhancing environmental awareness, this study offers insights into the types of recyclable materials households are more inclined to separate. These findings may inform the development of policies better tailored to the municipality's specific needs and characteristics.

Pay-as-You-Throw System

One policy implemented in various municipalities across different countries to address excess MSW production is the PAYT system [17]. This system is based on two fundamental principles [16]: the polluter-pays principle and the concept of shared responsibility. The implementation of this system is an important tool in MSW management policies, thereby reducing the amount of waste that is sent to the final destination and increasing the amount of selective waste [18]. The objectives of PAYT are simple and primarily involve encouraging the population to adopt sustainable habits to reduce waste production, to increase the fraction of selective materials and reduce the fraction of undifferentiated waste. As emphasised by [19], the effective implementation of a PAYT system can substantially enhance waste management operations by enabling more accurate collection of waste generation data, optimising collection frequencies and routing, and thereby contributing to sustainable development.

The waste tariff in the PAYT system is calculated based on actual production, not on a tariff indexed to water consumption or another system such as the number of residents, collection frequency, or even the area of occupation [20]. In this way, households pay according to the amount of waste they produce and the more undifferentiated waste they produce, the more they pay. As well as being fairer, this method provides a financial incentive for the population to promote separation at source and increase selective collection rates [21].

The PAYT system has several benefits. Firstly, it promotes environmental sustainability, as the incentive to reduce waste production increases the proportion of recyclable waste and reduces undifferentiated waste [14]. In addition, it contributes to economic efficiency, as well-developed PAYT systems generate the revenue needed to cover waste management costs [20]. Finally, it ensures social equity, as it is a fairer system in which those who produce less differentiated waste also pay less [22]. However, several disadvantages associated with the PAYT system can also be identified. These include the potential for a disproportionate burden on larger households [15], the potential to encourage waste tourism [10], and the increased complexity of designing and implementing a fee structure based on unsorted waste generation [20].

To implement the philosophy underlying the PAYT system, three models have most often been adopted [23]: the door-to-door collection model, the collective deposit container model and the pre-paid bag model. The first model consists of a consumer using an individual container to deposit waste, with container capacity determined by the weekly volume or weight

deposited, and a tariff applied based on the waste's volume or weight. The containers have a unique identifier that allows the quantity deposited to be recorded, and the variable tariff is calculated according to the quantity of undifferentiated waste deposited. The second model consists of consumers placing their undifferentiated waste in collective waste bins. Users have a magnetic identification card that allows them to use the system. When they put their waste in the container, the amount is measured by volume or weight, and they are charged for undifferentiated waste. The variable tariff is calculated according to the amount of undifferentiated waste deposited. In the third model, consumers have access to a pre-paid sack system. In this model, consumers buy labelled waste sacks to dispose of their unsorted waste, while specific labelled sacks for recyclable waste are also provided, usually free of charge.

MATERIALS AND METHODS

A case study research strategy, focused on understanding the implementation of the PAYT waste management system in Guimarães, Portugal, was used in this study. This strategy enabled a comprehensive analysis of the outcomes associated with the implementation of the PAYT system.

The study adopts a descriptive-exploratory approach, presenting quantitative data that illustrate the scope and impact of the project, alongside interpretative insights that contextualise and explain the observed results. This methodological combination is particularly well-suited to investigations of relatively underexplored phenomena, as it facilitates both detailed description and exploratory analysis of key characteristics and outcomes [24].

The analysis is based on secondary data from VITRUS Ambiente, a municipal company responsible for urban waste management, public sanitation, environmental monitoring, and oversight of public parking services within the municipality.

Portuguese Context

In Portugal, under traditional MSW management systems, households are charged uniform fees irrespective of the quantity of waste generated. In practice, most municipalities levy waste tariffs based on household water consumption [20]. This approach is largely justified by the lack of infrastructure enabling municipalities to accurately measure and differentiate domestic waste streams, thereby hindering the implementation of more efficient, quantity-based charging mechanisms. However, empirical evidence indicates that waste generation is not directly correlated with water consumption [25]. Consequently, such tariff structures provide little incentive for households to reduce waste generation, as fees are not linked to actual waste production [16].

Since Portugal acceded to the European Union in 1986, several legislative measures have been enacted to improve MSW management, particularly with regard to increasing the efficiency of MSW systems; closing open dumps; developing waste management infrastructure; reducing waste generation – especially hazardous waste, while promoting its reintegration into economic cycles; and fostering technological development [20].

In the Portuguese context, Decree-Law No. 102-D/2020 aimed to make it compulsory to de-index solid waste tariffs from water consumption. In this way, the waste tariff must be applied according to the amount of waste collected. This Decree-Law set a five-year implementation target: the PAYT system had to be adopted by all Portuguese municipalities by 2026. In 2024, Decree-Law no. 24/2024 was published, amending the General Waste Management Regime and the Legal Regime for Landfill of Waste, which states that as of 1 January 2025, tariffs for the commerce, services and catering sector must no longer be indexed to water consumption and that as of 1 January 2030, tariffs for the domestic sector must also no longer be indexed to water consumption, so PAYT systems must be adopted on these dates. In Portugal, the PAYT system was first implemented in 2016 by the municipality of Guimarães.

Since then, this system has been implemented in other Portuguese municipalities, initially using a preliminary study to inform its implementation and subsequent analysis.

Case Study Description

In this study, to assess the impact of using the PAYT waste management system, the municipality of Guimarães, located in northern Portugal and considered the cradle of the Portuguese nation, was used as a case study. This municipality has around 157,000 inhabitants, a geographical area of 241 km² and a population density of 651 inhabitants/km². It is a municipality where manufacturing has a significant weight in its economy, particularly in the textile and clothing sector. With a rich historical and cultural heritage, the municipality has an impressive medieval centre full of iconic monuments. The historic centre of Guimarães (HCG) is recognised as a UNESCO World Heritage Site, enchanting visitors with its picturesque streets, deep-rooted festivities and profound connection to national history.

Interest in adopting the new PAYT waste management paradigm in the HCG arose from the implementation of a pilot project, the results of which were presented in the study by [26]. The PAYT system has been in operation in the municipality of Guimarães since April 2016, in a pioneering way in Portugal, where it has achieved positive results in the environmental field.

The first phase of implementing the PAYT system was in the HCG (known as zone A), and it was then extended to two more zones, zone B (streets adjacent to the HCG within the walls) and zone C. This extension follows the success achieved in meeting all the targets set over the years. Since March 2023, the PAYT system has covered all users of the Oliveira, São Paio and São Sebastião Parish Council. Waste collection in the PAYT areas is mixed, with door-to-door and deep-container collection. Users are divided into domestic users (DU) and non-domestic users (NDU). The latter are subdivided according to the typology shown in Table 1.

Table 1. Characterisation of the types of NDU

Typology	Description
A	Café, bar, bakery, patisserie
B	Restaurant
C	Retail shop (e.g., clothes, handicrafts, supermarket and service providers)
D	Hotel, hostel or guest house
E	Institutions, associations and schools

The PAYT project is divided into two different methods. Note that in the PAYT system, the variable waste tariff is not indexed to water consumption, but to waste production. Two methods have been implemented: method A and method B. The first consists of the variable tariff being indexed to waste production through the purchase of bags for unsorted and organic waste, i.e., the initial method. In the second, the variable tariff is calculated by estimating production by user type, with the tariff paid directly on the water bill. With this method, it is not compulsory to buy sacks for unsorted and organic waste. However, if the user wishes to change the method, they must request a change.

Analytical Procedures

The analysis undertaken in this study is grounded in an assessment of the evolution of municipal waste collection within the context of the implementation of the PAYT system. A comparative framework was employed, considering two distinct temporal periods representative of different stages in the system's development. The first period corresponds to the years 2015–2017, where 2015 is the year prior to the implementation of the PAYT system, 2016 marks the initial year of implementation, and 2017 represents the first complete year of system operation. The second period of analysis was 2021–2023 reflecting a more mature and

consolidated phase of implementation. It is important to note that the PAYT system was introduced in April 2016; consequently, the data for that year cover only the period from April to December. As such, 2016 is treated as a transitional year, and its interpretation is undertaken with appropriate caution, rather than as directly comparable with full calendar years.

Data were treated and analysed using Microsoft Excel[®] software, according to the following calculations:

- absolute values, expressed in tonnes of waste collected by waste type;
- relative values, enabling the calculation of proportions between undifferentiated waste and separately collected recyclable waste;
- ratio-based indicators, used to estimate the percentage increase in recycling following the implementation of the PAYT system within the operational areas, thereby facilitating the identification of changes in waste separation behaviours.

In addition, an indicative estimate of avoided CO₂ emissions was prepared based on observed variations in the quantities of waste collected for recycling and representative emission factors. This component of the analysis aimed to complement the interpretation of results by providing an approximation of the environmental impacts associated with implementing the PAYT system.

Finally, adherence to the PAYT system is analysed according to user type, distinguishing between domestic and non-domestic users. Within this second category, five user typologies were further distinguished based on the expected volume of waste produced (see [Table 1](#) above).

RESULTS

This section presents the results of the implementation of the PAYT system and is structured as follows. First, a comparative analysis is conducted for the period 2015–2017, given that the PAYT pilot was initiated in 2016. This approach enables an initial assessment of the effects of PAYT implementation by comparing municipal waste collection in the year preceding implementation, the year of implementation, and the subsequent year. Second, a comparative analysis is undertaken for the period 2021–2023, during which the PAYT system was extended to adjacent areas and had reached a greater level of operational maturity. In this phase, more granular data – specifically, monthly waste collection figures – are employed, reflecting increased experience with the system. Third, an estimation of avoided CO₂ emissions is presented to evaluate the associated environmental impacts. Finally, the outcomes of PAYT implementation are analysed from the perspective of different user categories.

Analysis of Years 2015–2017

This subsection presents the results of a comparative analysis conducted for the years 2015, 2016 and 2017, corresponding respectively to the year preceding the implementation of the PAYT system, the year in which its implementation commenced, and the first full year of operation.

First, the overall distribution between undifferentiated waste and separately collected waste was analysed in order to assess structural changes in the composition of collected waste ([Figure 1](#)). In 2015, prior to the implementation of the PAYT system, a clear predominance of undifferentiated waste was observed. This fraction totalled 821 t (tonnes), representing approximately 87% of total annual waste generation (943 t). By contrast, separately collected waste amounted to only 122 t, corresponding to around 13% of the total. These figures indicate a low level of source separation prior to the introduction of the PAYT system.

In 2016, during the initial implementation phase of the PAYT system, a marked shift in waste collection structure was observed. It should be noted, however, that the system only became operational in April 2016. Therefore, the data presented refer solely to the period from April to December. Notwithstanding this limitation, the results indicate a reduction in the

relative share of undifferentiated waste, which totalled 538 t, corresponding to approximately 66.5% of total waste generation during the analysed period (809.26 t). Conversely, separately collected waste increased to 270 t, representing approximately 33.4% of the total. Although 2016 constitutes a transitional year, these values already suggest a substantial shift in users' disposal behaviour.

In 2017, corresponding to the first full year of PAYT system operation, the altered collection pattern remained evident. Undifferentiated waste totalled 628.14 t, representing approximately 66.7% of total annual generation (941.46 t), while separately collected waste totalled 313.32 t, accounting for approximately 33.3%. When compared with 2015, a clear structural transformation is evident, reflected in a substantial reduction in the relative share of residual waste and a significant increase in separate collection. Nevertheless, it is important to emphasise that, even following the initial implementation of the PAYT system, undifferentiated waste remained the dominant fraction in total collection. In absolute terms, the quantity of undifferentiated waste collected continued to exceed that of separately collected waste.

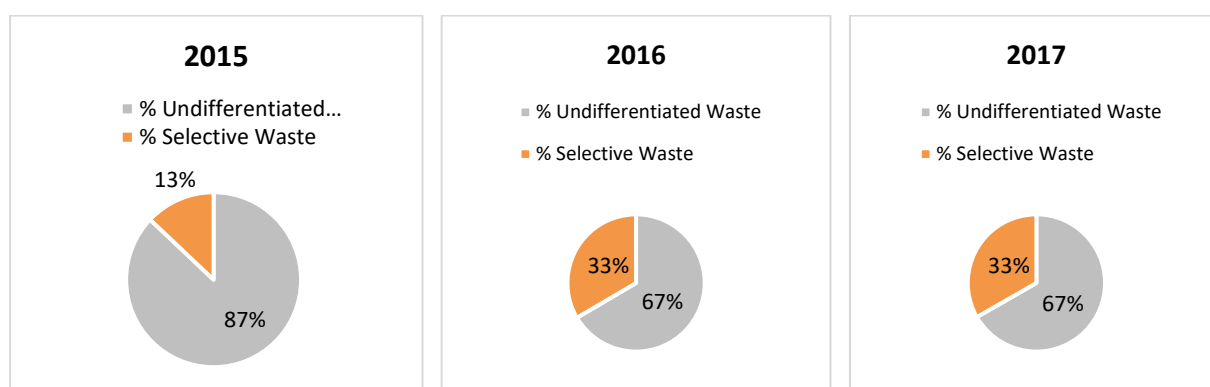


Figure 1. Percentage of solid waste collected in 2015, 2016, and 2017

Overall, the comparison between 2015 and 2017 reveals a clear transformation in the structure of waste collection, characterised by a decline in the predominance of the undifferentiated waste and an increase in the selective component. Although the 2016 data must be interpreted with caution, as they correspond to a partial implementation period, the observed evolution across the three years points to a positive initial effect associated with the introduction of the PAYT system. It is nevertheless important to underline that, during this initial phase of implementation, undifferentiated waste collection continued to exceed separate collection in absolute terms. This aspect is particularly relevant when compared with more recent years, analysed in the subsequent subsection, in which this trend is no longer observed, reflecting a more consolidated system performance and a more profound change in users' separation behaviour.

Analysing by type of waste collected (Figure 2), the evolution of undifferentiated waste demonstrates a notable decrease following the implementation of the PAYT system. In 2015, this fraction amounted to 821 t, decreasing to 538 t in 2016 and to 628.14 t in 2017. Although the 2016 value is not directly comparable due to its partial-year coverage, the comparison between 2015 and 2017 indicates a reduction of approximately 192.86 t, suggesting a significant shift in users' disposal practices and increased participation in waste separation.

Regarding glass, a substantial increase was observed over the study period. In 2015, 67 t were collected, rising to 147.72 t in 2016 and to 174.44 t in 2017. This trend suggests a marked improvement in the separation of this type of waste, indicative of increased user participation in selective collection following the introduction of the PAYT system.

The paper and cardboard waste collection also exhibited positive growth. Collection increased from 33 t in 2015 to 68.54 t in 2016 and to 84.68 t in 2017. As with other selectively

collected waste, this upward trend reinforces the interpretation that the PAYT system contributed to improved efficiency in source separation.

Similarly, plastic waste showed an increase between the pre-PAYT period and subsequent years. In 2015, 22 t were collected, increasing to 54.30 t in 2016 and remaining at comparable levels in 2017 (54.14 t). Although the change between 2016 and 2017 appears relatively stable, the overall increase compared with the pre-implementation period remains substantial.

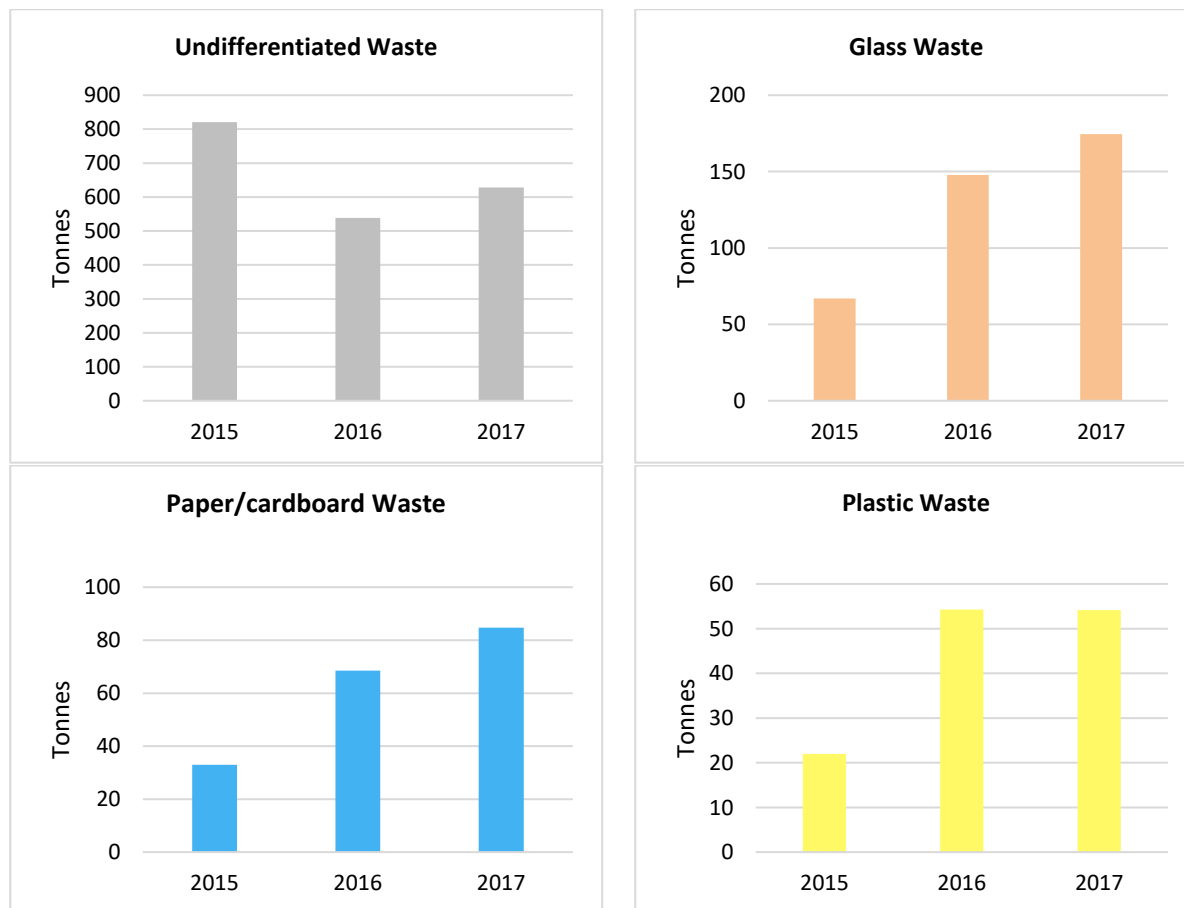


Figure 2. Evolution of waste collection by type in the period 2015–2017

In summary, the analysis by type of waste collected confirms that the implementation of the PAYT system was associated not only with a reduction in the undifferentiated component but also with a consistent increase in the principal waste selectively collected. These findings support the interpretation that the system contributed to a structural reorganisation of municipal waste management in the study area, promoting more effective source separation behaviours among users. However, this initial phase remained characterised by the predominance of undifferentiated waste in absolute terms. Comparison with more recent years, presented in the following subsection, will allow for a clearer assessment of the system’s progression towards a model in which this predominance is progressively diminished.

Analysis of Years 2021–2023

This subsection analyses data on the tonnes of municipal solid waste (MSW) collected in the PAYT area in 2023 and compares it with previous years. These figures come from the service sheets completed by the employees responsible for collection and the weighings obtained at unloading.

Undifferentiated waste versus selective waste. **Figure 3** shows the percentage of MSW collected in 2022 and 2023. It can be seen that in 2022, selective waste collection accounted for

47%, while undifferentiated collection accounted for 53%. It should be noted that selective collection means collecting paper/cardboard, packaging, glass and bio-waste (organic waste). By 2023, the collection of undifferentiated waste will account for only 17%, and selective collection will account for 83%.

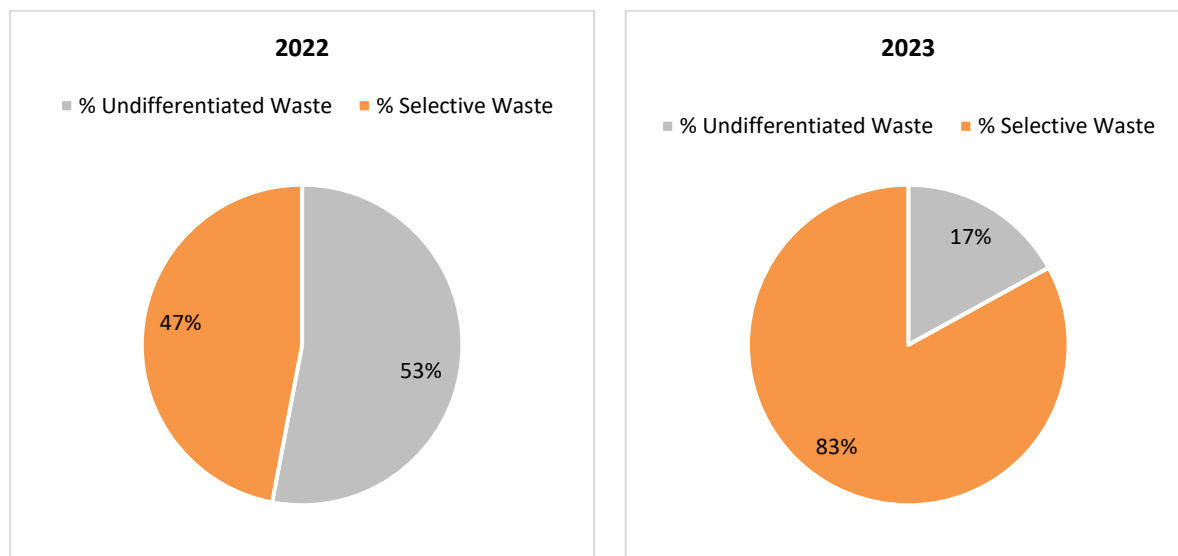


Figure 3. Percentage of solid waste collected in 2022 and 2023

In 2023, only 539.24 t of undifferentiated and 2,542.56 t of selective waste were collected. Compared to 2022, there was a significant decrease in the tonnes of undifferentiated waste collected, accompanied by a corresponding increase in the tonnes of selective waste. In 2022, 2,074.58 t of undifferentiated waste and 1,939.82 t of waste from selective collection were collected. The 36% decrease in tonnes of undifferentiated waste from 2022 to 2023 can be explained by greater adherence and understanding among the population to the distinction between undifferentiated waste and the selective collection of organics.

The following subsections analyse the types of MSW in more detail, starting with undifferentiated waste, then paper and cardboard, glass, and plastic, and ending with organic waste. At the end, the results from the users' perspective are also analysed.

Undifferentiated waste. In 2023, a total of 539.24 t of undifferentiated waste was collected, averaging 44.94 t per month. Looking at the data in [Figure 4](#) on undifferentiated waste collection, the month with the highest waste production was January (131.12 t), and the month with the lowest collection was April (7.18 t).

Throughout 2023, the number of tonnes collected in January was an exception, as in the remaining months it was always less than half of that collected in January. Apart from January, only three months exceed 40 t collected each month: February, with 64.08 t; June, with 57.04 t; and December, with 44 t. The remaining eight months have collected less than 40 t each. January is a month with a large amount of undifferentiated waste, as end-of-year festivities lead to improper waste separation and recycled waste ending up in the undifferentiated waste stream. Because the festivities are right at the end of the year and because of the collection days, these quantities are mostly collected in January and associated with that month.

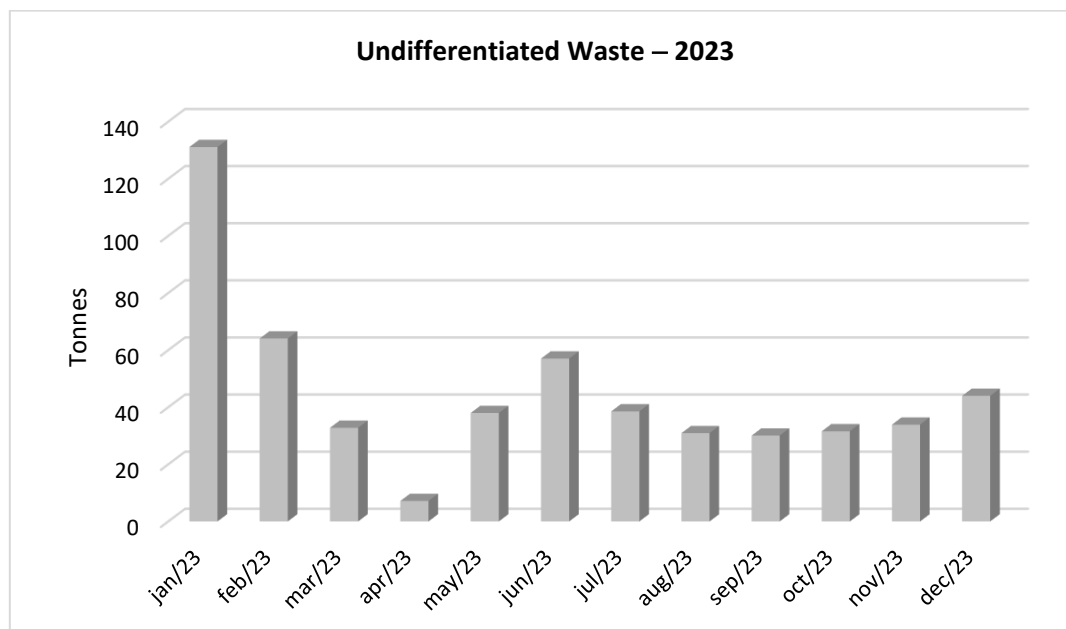


Figure 4. Collection of undifferentiated waste in the PAYT area in 2023

Figure 5 shows the evolution of the quantities of undifferentiated waste collected in 2021, 2022 and 2023. There is a fairly significant decrease between 2023 and the two previous years, indicating that the population is more committed to these circular-economy projects that benefit the environment and users. The average number of tonnes dropped significantly over the three years under analysis. In 2021, an average of 193 t of undifferentiated waste was collected per month; in 2022, the monthly average was 173 t; and in 2023, a very positive impact was observed with an average of only 45 t per month.

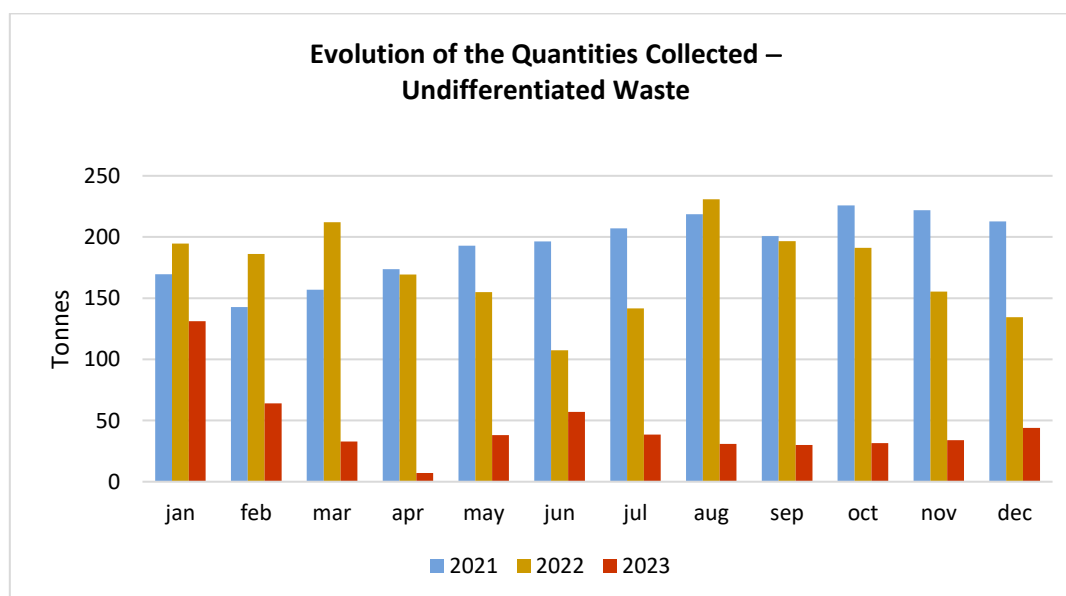


Figure 5. Evolution of the quantities collected (undifferentiated solid waste)

Glass waste. Analysing the glass fraction, a total of 322.50 t of glass was collected in 2023, with a monthly average of 26.88 t. **Figure 6** shows that three months stand out for the highest number of tonnes collected: May, June, and August. The figures for the latter month can be explained by the fact that there is a higher concentration of people, both residents and tourists, as it is the holiday season. The month with the least amount collected was April (21.24 t).



Figure 6. Selective collection of glass in the PAYT area in 2023

Figure 7 shows the evolution of the quantities of glass collected in 2021, 2022 and 2023. It can be seen that over these three years, the number of tonnes collected varies month to month, with August recording the most tonnes. The months with the greatest amount of glass waste collected in 2023, compared to the previous two years, were February, May, June, September, and November.

In 2021, the average monthly collection was 25 t; in 2022, 26 t; and in 2023, 27 t. From year to year, there has been only a 1-tonne increase in the monthly average, i.e., there is not a very significant variation in the quantities of glass collected, and these figures can be justified in two ways. On the one hand, glass was the first material to be recycled, and the first recycling centre was set up for glass, so people were already used to separating this waste. On the other hand, glass has always been the most recycled waste, since it doesn't cause collection uncertainty like paper/cardboard and plastic.

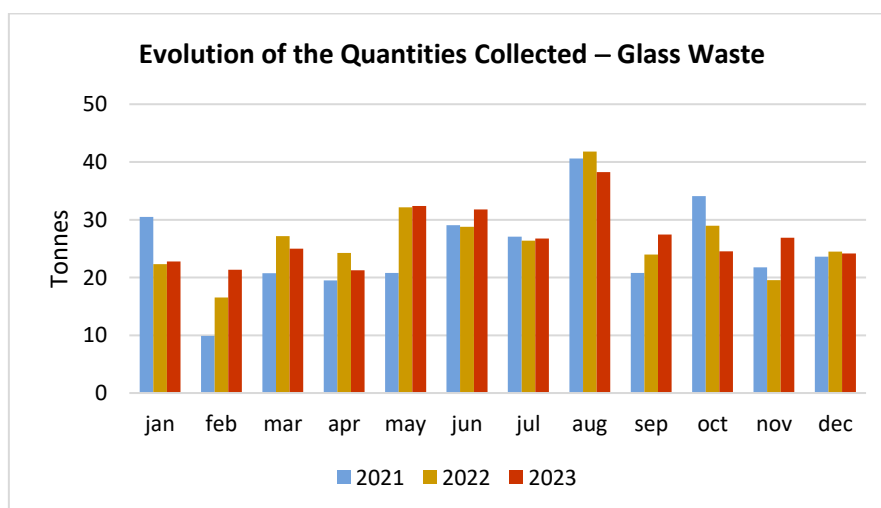


Figure 7. Evolution of the glass waste quantities collected

Paper/cardboard waste. Throughout 2023, a total of 531.58 t of paper/cardboard were collected, with a monthly average of 44.30 t. The months with the highest tonnage of paper/cardboard collected are January, March and December. The figures for the last month of the year can be explained by the fact that it is a month in which a lot of this selective waste is produced, as it is the festive season (Christmas and New Year). Looking at the data on selective

paper/cardboard waste collection in **Figure 8**, the month with the highest waste production was December (52.06 t), and the month with the lowest collection was February (37.46 t).

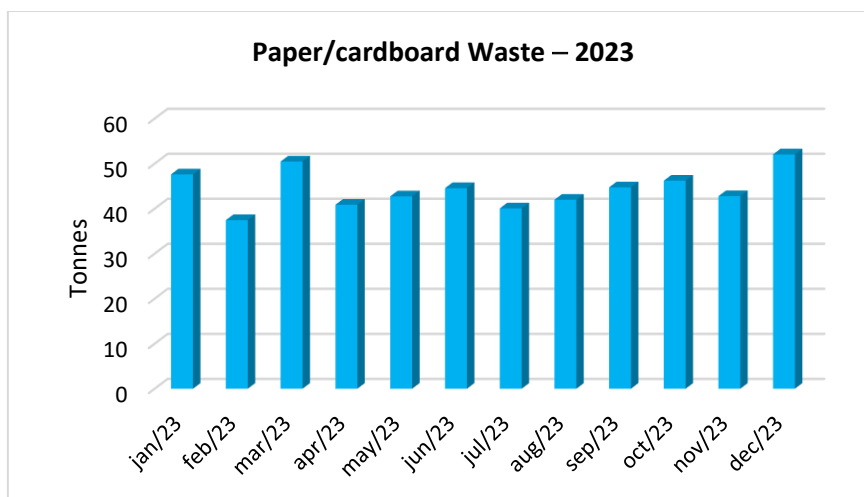


Figure 8. Selective Collection of Paper/Cardboard in the PAYT area in 2023

Figure 9 shows the evolution of the quantities of paper/cardboard waste collected in 2021, 2022 and 2023. There is an increase in tonnes collected in practically every month in 2023 compared to previous years, except for April, July, and November. In 2021, the monthly average was 38 t; in 2022, 42 t; and in 2023, 44 t – increasing average values, indicating a positive trend.

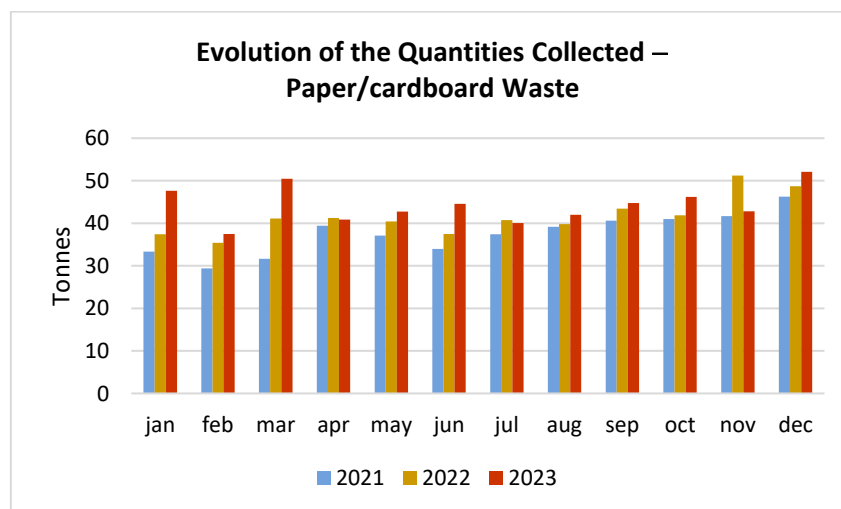


Figure 9. Evolution of the Quantities Collected (Paper/Cardboard waste)

Plastic waste. Looking at plastic waste, in 2023, a total of 233.20 t was collected, with a monthly average of 19.43 t. Looking at the data on selective plastic waste collection in **Figure 10**, May had the highest waste production (29.16 t), while February had the lowest (14.88 t). The months of January (20 t), May (29.16 t), August (19.46 t), October (20 t) and November (21.24 t) had amounts equal to or greater than the monthly average of tonnes of this waste collected. May saw the highest tonnage collected, although the transition from April to May saw increases across all selective collections, with plastic showing a very significant increase. The increase in waste production from one month to the next cannot be the only justification for this figure; it can also be explained by the placement of plastic containers at the University of Minho’s Azurém campus as part of the Deucalion supercomputer project. These containers were collected in May, which significantly inflated the total tonnage collected.

Although the university is not in the PAYT zone, as it is on the border, these figures were attributed to plastic waste in this area.



Figure 10. Selective collection of plastic in the PAYT area in 2023

Figure 11 shows the evolution of the quantities of plastic waste collected in 2021, 2022 and 2023. There is an increase in tonnes collected in almost every month in 2023 compared to previous years, except December. In 2021, the monthly average was 14 t; in 2022, 16 t; and in 2023, with a higher average, a good indicator and once again meeting the objectives of this type of project, 19 t were collected each month.

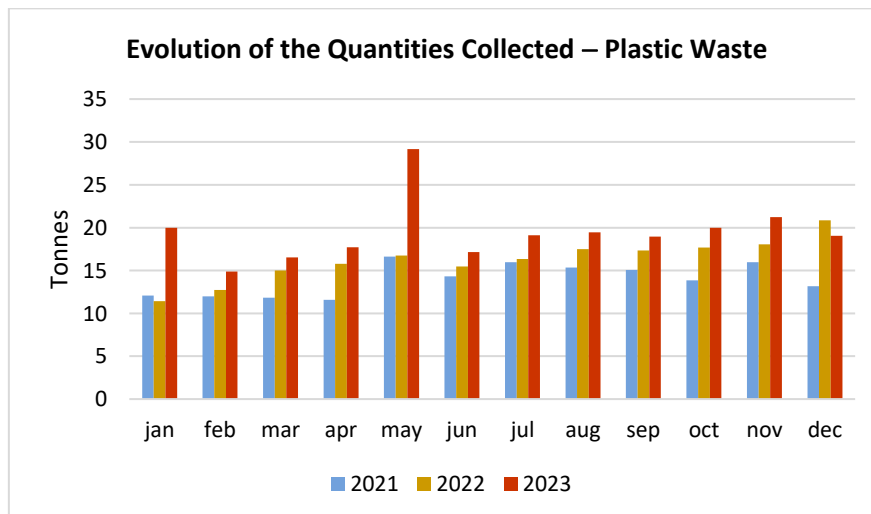


Figure 11. Evolution of quantities collected (plastic waste)

Organic waste. Throughout 2023, a total of 1,455.28 t of organic waste was collected, averaging 121.27 t per month. Analysing the data on the selective collection of organic waste (**Figure 12**), the month with the highest waste production was October (152.76 t) and the month with the lowest collection was July (93.90 t). The months that stand out in terms of the number of tonnes collected throughout the year are January, October, November and December. In October, the leaves start to fall, and many people prune, which leads to the waste being placed in the organic waste bins. This behaviour has been witnessed by the employees who collect the MSW. From October until around the end of the year, this behaviour is seen, which justifies the figures obtained. As seen above, in December waste production increases

due to end-of-month festivities, and consequently food waste increases, reflected in the increase in weighing in December and January.

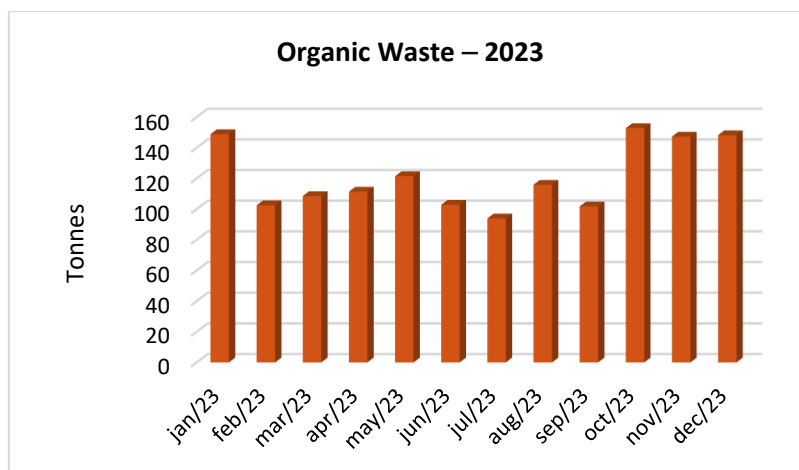


Figure 12. Selective collection of organics in the PAYT area in 2023

As data on organic waste tonnage began only in January 2022, **Figure 13** shows the evolution of its collection from that date through December 2023. In 2022, the monthly average of tonnes of organic waste collected in the PAYT area was 77 t, and in 2023, the average was 121 t monthly. The monthly average of tonnes collected in 2022 in the PAYT area was calculated over the twelve months, since collection was continuous. Although the monthly average is higher in 2023, the records for 2022, especially for the last few months of the year (from August to December), are better as they show a greater number of tonnes collected, except for November.

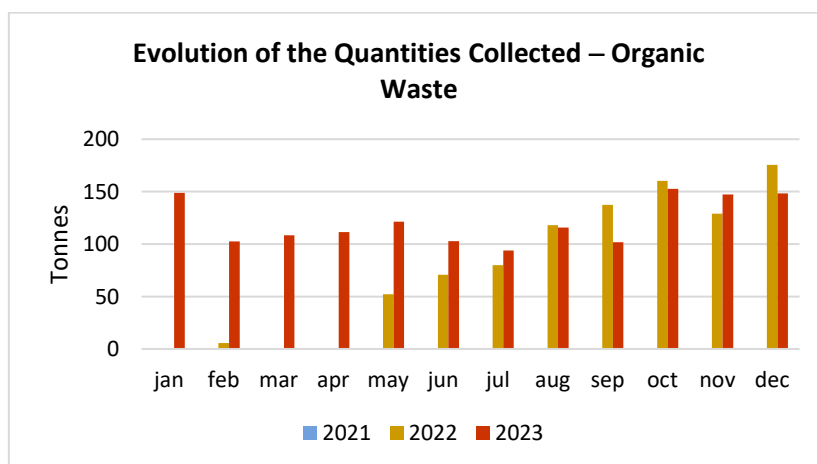


Figure 13. Evolution of quantities collected (organic waste)

The collection of organic waste has been in place for only a relatively short time, since 2022, while the collection of other MSW (paper/cardboard, plastic and glass) has been in place since 2016. It is therefore normal that, unlike analysing the evolution of the quantities collected for the other waste, there should be variation in the values, and the indicators should not be as positive. However, these results were to some extent expected given that this is a new selective collection and that the population sometimes shows resistance to joining new projects.

Avoided CO₂ Emissions

To complement the analysis of the impacts of implementing the PAYT system, an indicative estimate of avoided CO₂ emissions was undertaken based on changes in both the

composition and quantity of waste collected over the period under analysis. The estimation was carried out by considering the variation in the quantities collected for each waste fraction between selected reference years, applying representative emission factors for each material type, using eq. (1):

$$\text{Avoided } CO_2e = \sum (\Delta Q_i \times EF_i) \quad (1)$$

where ΔQ_i denotes the variation in the quantity (in tonnes) of waste fraction i between the years analysed, and EF_i represents the corresponding emission factor (in tCO₂e per tonne), associated with the treatment or recovery of that waste fraction.

Initially, a comparison was conducted between 2015, the period before the implementation of the PAYT system, and 2017, the first full year of system operation. The results indicate a substantial reduction in undifferentiated waste, with a decrease of approximately 192.86 t, accompanied by a marked increase in selectively collected fractions, namely: +107.44 t of glass, +51.68 t of paper and cardboard, and +32.14 t of plastic. Based on these variations, and through the application of indicative emission factors for each waste fraction [27], an overall reduction of approximately 229 tCO₂e was estimated. This value reflects the combined effect of the reduction in undifferentiated waste, typically associated with higher emissions, and the increase in separate collection, which enables material recovery and, consequently, reduces emissions linked to the production of virgin raw materials.

Furthermore, an analysis was conducted for a more recent period, comparing 2021 and 2023, which are representative of a more mature and consolidated phase of the PAYT system implementation. The results reveal a very significant reduction in residual waste, with a decrease of approximately 1,780.10 t, accompanied by increases in the principal selectively collected fractions: +24.12 t of glass, +80.62 t of paper and cardboard, and +65.40 t of plastic. In addition, this period is characterised by the introduction and substantial growth of the biowaste fraction, which reached 1,455.28 t in 2023, representing a relevant additional component in waste recovery. Based on these variations, an overall reduction of approximately 1,367 tCO₂e was estimated.

The comparison between the two periods highlights a progressive improvement in the environmental performance associated with the PAYT system. While the initial implementation phase (2015–2017) already demonstrated positive emission reductions, the more recent phase (2021–2023) has a considerably greater impact. This development reflects increased system maturity, the consolidation of waste separation behaviours, and the incorporation of additional fractions, particularly biowaste.

Type of Users

This subsection presents the results of implementing the PAYT system from the perspective of the number of users. By the end of 2023, the PAYT area encompassed 6,293 users, of which 4,471 were DUs, and 1,822 were NDUs. Of these NDU, 123 belong to Type A, 143 to Type B, 1,369 to Type C, 127 to Type D and 60 to Type E.

Users of the PAYT system choose the payment method: either via the PAYT bag purchase system (Method A) or via a production estimate, with a default tariff (Method B). In 2022, 207 requests to change method (from method B to method A) were recorded, while in 2023, 559 were recorded. Of these 559 change requests, 166 users did not buy bags, so after analysing them, they migrated to the previous method. This significant increase in requests for a change of method demonstrates the population's greater support for this circular economy project, which has a major impact on the environment and the population. In 2022, 273 users were enrolled in method A. **Figure 14** shows the percentages for DU and NDU, with DU accounting for 62% and NDU for 38%.

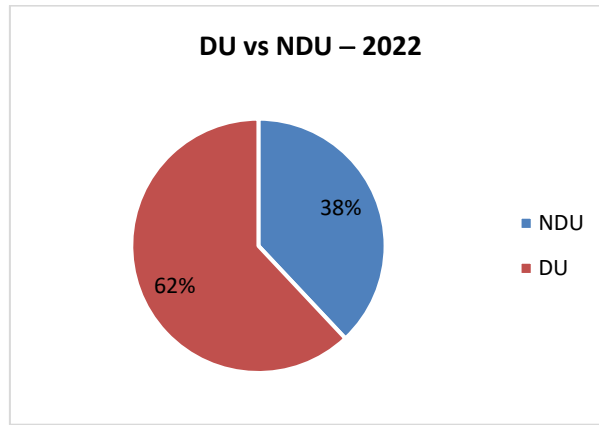


Figure 14. Percentage of DU vs. NDU (2022) in method A

Type A is responsible for 27% of NDUs, contributing 28 establishments; type B is represented by 27% of NDUs, with 27 facilities; type C has 26% of NDUs, collaborating with 27 entities; type D has 13% of NDUs, accounting for 13 lodgings and, finally, type E is represented by 7%, with 7 institutions. [Figure 15](#) shows the number of users per NDU type.

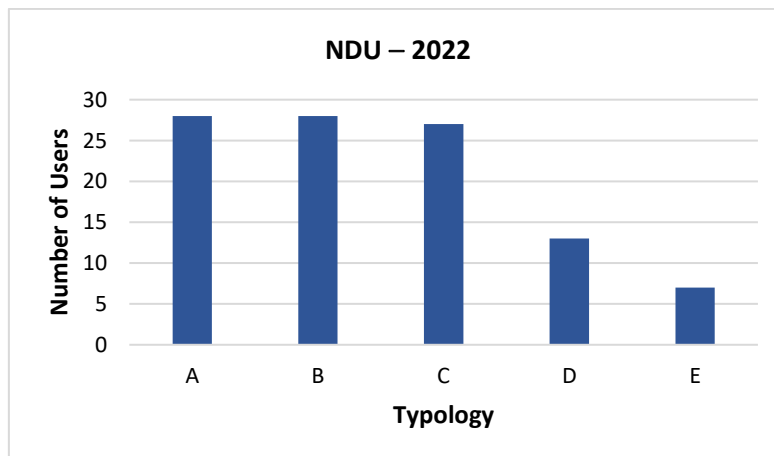


Figure 15. Number of NDU 2022 in method A by typology

Comparing 2022 with 2023, we see a significant increase in the number of users of method A, driven by a growing number of requests to switch to it. It can be seen that in 2022, only 273 users were assigned to the bag purchasing method, and in 2023, this increased to 627. DU users account for 84% of users, while NDU users account for 16%, as can be seen in [Figure 16](#).

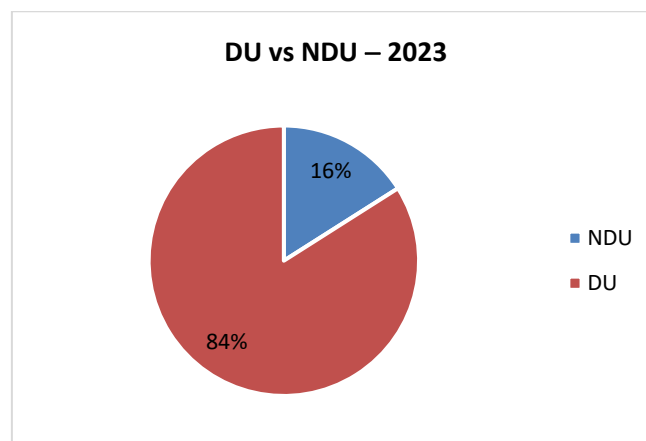


Figure 16. Percentage of DU vs. NDU (2023) in method A

Type A is responsible for 27% of NDUs, contributing 28 establishments; type B is represented by 25% of NDUs, with 26 facilities; type C has 20% of NDUs, collaborating with 20 organisations; type D has 11%, with 11 accommodations; finally, type E is represented by 17%, with 17 institutions. **Figure 17** shows the number of users associated with each NDU type.

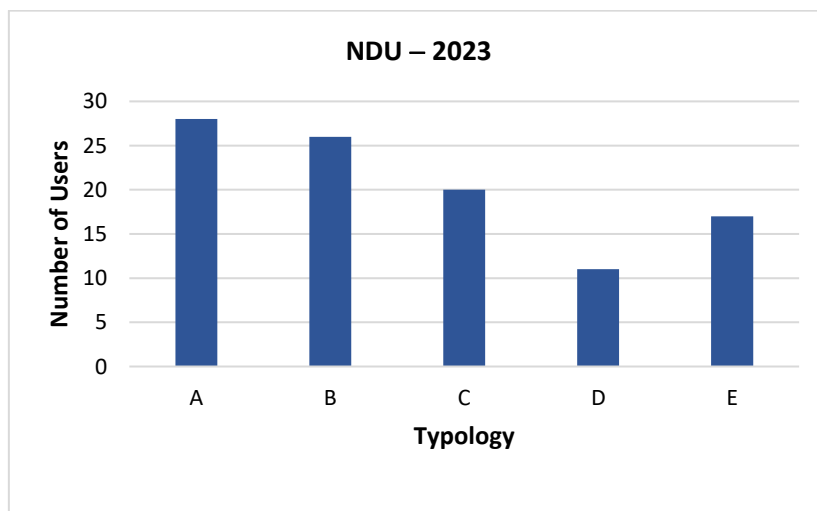


Figure 17. Number of NDU 2023 in method A by typology

By way of conclusion, this significant increase is essentially due to growth in DUs, as this user type has seen the greatest growth. The number of NDU users has remained constant. The fact that a user is included in method A implies that bags will be purchased. However, there is only one point of sale, which may, to some extent, limit users from requesting a change of method because the opening hours coincide with the working hours of the majority of the population, so that they are unable to make regular and continuous purchases of bags and migrate back to method B. It should also be added that all migrations are notified in advance and that users have the opportunity to regularise non-compliance.

DISCUSSION

This study contributes to a more nuanced understanding of waste management within a local context, providing some empirical evidence of the successful implementation of circular economy initiatives.

An important characteristic of the PAYT system is its direct linkage between waste collection fees and the amount of waste generated, which has been shown to contribute to reductions in household solid waste and to increases in recycling activity [16]. Although the analysis is based on data from a relatively short observation period, this effect was also observed following the implementation of the PAYT system in Guimarães. As demonstrated in the previous section, the results indicate a clear reduction in the quantity of undifferentiated waste collected, accompanied by an increase in the selective collection of recyclable waste. Furthermore, the findings of this study underscore an additional advantage of the PAYT system. By improving the degree of source separation of recyclable waste, the system enhances efficiency in the municipal solid waste recycling process [10]. Indeed, one of the persistent challenges facing the recycling system in Portugal is the inadequate separation of household recyclables, which substantially limits the overall effectiveness of the recycling process.

The results also highlight the need to foster behavioural change, which requires active and sustained interaction with the local population [17]. Direct engagement strategies are essential to ensure that individuals develop a sense of proximity to the issue and are consistently encouraged to adopt environmentally responsible practices. The achievement of the project's objectives can be attributed to the population's awareness of environmental issues and their

willingness to collaborate, underscoring the significance of public participation in the success of sustainable waste management efforts. However, some authors (e.g., [15]) have highlighted that public resistance remains a significant barrier to the widespread adoption of PAYT, emphasising the need for effective and transparent communication strategies to ensure public understanding and support for the implementation of the PAYT system.

While the positive outcomes observed in this study following the pilot implementation of the PAYT system are partly attributed to its favourable acceptance among the local population, further research is required to examine in greater depth how receptiveness to PAYT varies across different sociodemographic groups. Existing evidence in the literature remains inconclusive. For instance, a study conducted in Grenoble, France [15] reported higher receptiveness among younger residents, individuals with above-median income, and those holding at least a master's degree. In contrast, a study in Beijing, China [23] found that acceptance of the PAYT system was higher among older residents and those with lower educational attainment. Accordingly, these authors emphasised that the successful implementation of a PAYT system depends to a large extent on residents' comprehensive understanding of the scheme and their sustained cooperation, thereby highlighting the critical role of awareness-raising campaigns conducted by local public authorities.

Another challenge that local decision-makers must address is the phenomenon commonly referred to as waste tourism. This practice occurs when households dispose of their waste in other households' containers or in natural environments to avoid fees associated with PAYT schemes [15]. To mitigate this issue, [14] argue that integrating sustainability education into school environments and curricula can foster the social awareness and pro-environmental behaviours required for the effective functioning of PAYT systems.

CONCLUSIONS

The circular economy presents a fundamental challenge to the conventional linear model of production and consumption, which is predicated on the sequential processes of resource extraction, production, use, and disposal. This paradigm shift offers the potential to substantially mitigate environmental impacts while simultaneously generating new economic opportunities and fostering long-term sustainability. It aims to reconcile economic growth with environmental protection and social equity, ensuring the availability of resources for future generations, reducing ecological degradation, and sustainably enhancing the quality of life.

Circular economy initiatives play a critical role in facilitating the transition toward a more sustainable economic system. The recovery and recycling of waste remain central to environmental protection efforts and contribute to reducing the financial burden associated with the collection, transport, and treatment of urban waste. Consequently, the widespread adoption and scaling of circular economy projects are imperative for advancing a more sustainable future. However, the circular economy should not be viewed merely as an alternative model but as an urgent and necessary framework for constructing an economy that respects planetary boundaries and supports the well-being of both present and future generations.

The circular economy project (PAYT system) examined in this study demonstrates positive outcomes for both the environment and the local population. Environmentally, the initiative contributes to reducing landfill dependency by promoting alternative waste management strategies that minimise final waste disposal and reduce CO₂ emissions. Socially and economically, the implementation of the PAYT system influences residents' behaviour and generates economic benefits. This system introduces a more equitable model, charging users based on the actual volume of waste they generate rather than water consumption, thereby encouraging waste reduction and fostering greater accountability for waste.

This study has several limitations. An important one is that it is mainly a descriptive and exploratory study, focused on analysing the quantity of waste collected in the municipality of

Guimarães after the implementation of a pilot project for the PAYT system. Therefore, the conclusions drawn from the project results should be interpreted with caution. More research is needed to fully understand the reasons for the success of implementing that system. Another limitation is that, although a longitudinal study was undertaken, data were collected for only 3 years. Thus, to conduct a more robust analysis and determine whether an effective behavioural change has occurred, a study should be conducted over a longer time period.

PAYT systems have been promoted as an effective policy instrument to encourage waste reduction and recycling. However, the successful implementation of PAYT systems largely depends on public acceptance and residents' willingness to participate. Therefore, as future research, it is suggested that a study be conducted to understand citizens' perceptions, attitudes, and behavioural intentions regarding the implementation of PAYT systems at the municipal level. In other words, it aims to understand residents' willingness to adopt a PAYT-type waste management system and the factors that influence their acceptance or resistance.

ACKNOWLEDGMENT

This work has been supported by FCT – Fundação para a Ciência e Tecnologia within the R&D Unit Project Scope UID/00319/2025 – Centro ALGORITMI (ALGORITMI/UM) <https://doi.org/10.54499/UID/00319/2025>.

NOMENCLATURE

Abbreviations

DU	Domestic Users
EF	Emissions Factor
EU	European Union
HCG	Historic Centre of Guimarães
MSW	Municipal Solid Waste
NDU	Non-Domestic Users
PAYT	Pay-as-You-Throw

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Paper submitted: 04.02.2026
Paper revised: 19.04.2026
Paper accepted: 01.05.2026