Journal of Sustainable Development of Energy, Water and Environment Systems

http://www.sdewes.org/jsdewes

Year 2026, Volume 14, Issue 4, 1140731

Original Research Article

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

Ângela Pereira [1], Jorge Cunha*[2]

[1]Department of Production and Systems, University of Minho, Campus de Azurém, Guimarães, Portugal
e-mail: pg49135@alunos.uminho.pt

[2]ALGORITMI Research Center, University of Minho, Campus de Azurém, Guimarães, Portugal
e-mail: jscunha@dps.uminho.pt

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 aimed at decoupling economic growth from resource consumption by promoting waste prevention, efficient resource use, and the recovery and regeneration of materials throughout their life cycle. This study presents the outcomes of a circular economy–oriented waste management initiative, namely 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 waste separation and recycling practices among households. 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 and 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 a heightened intensity of economic activities and a corresponding rise in waste generation and its associated challenges [1]. Waste refers to materials discarded due to their perceived loss of utility or economic value [2]. It represents a significant environmental, social,

* Corresponding author

and public health concern, necessitating the urgent adoption of innovative management strategies and sustainable alternatives [3].

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. Following their use, these products are typically discarded, resulting in 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 the coordination of 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 aimed at minimising 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].

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 the lifespan of products and minimise the volume of waste produced, thereby encouraging the prioritisation of waste prevention, reuse, and recycling over landfill disposal. Landfilling is deemed the least desirable option due to its environmental implications, including the irreversible loss of resources 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 within the field of 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, assume particularly importance the efficient management of municipal solid waste (MSW) [14]. Traditionally, in the waste tariff system adopted in many municipalities there is no direct link between the waste generated and the price charged to collect waste [15]. Therefore, there is no incentive for households and commercial businesses to reduce the amount of waste generated. However, as emphasised by [16], differentiated fee systems increasingly support waste reduction by allocating waste management costs proportionally to

the amount of waste produced. One waste management system that has been implemented by several municipalities in 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 remains a limited number of 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 the framework of a circular economy model. 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 contributes to addressing this gap by providing context-specific insights into the environmental impacts of such a system, thereby supporting the environmental advancement of urban areas. Furthermore, given that source separation of waste is widely regarded as a key strategy for addressing the growing generation of urban waste and for enhancing environmental awareness, this study offers insights into the types of recyclable materials that households are more inclined to separate. These findings may inform the development of local policies that are more effectively tailored to the specific needs and characteristics of the municipality.

Pay-as-You-Throw system

One of the policies that has been implemented in various municipalities in different countries to deal with the excess production of MSW is the PAYT system [17]. This system is essentially based on the application of 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 mainly involve encouraging the population to adopt sustainable habits to mitigate waste production and, within this, reduce the fraction of undifferentiated waste and increase the fraction of selective materials. As emphasised by [19], the effective implementation of a PAYT system can substantially enhance waste management operations by enabling more accurate waste generation data collection, optimizing collection frequencies and routing, and thereby contributing to sustainable development.

The waste tariff in the PAYT system is calculated according to actual production and not based on a tariff indexed to water consumption, or through 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 leads to an increase in the proportion of recyclable waste, as well as a reduction in undifferentiated waste [14]. In addition, it contributes to economic efficiency, since well-developed PAYT systems generate the revenue needed to cover the costs of waste management [20]. Finally, it ensures social equity since it is a fairer system in which those who produce less undifferentiated waste also pay less [22]. However, several disadvantages associated with the PAYT system can also be identified. These include the potential disproportionate burden placed on larger households [15], the possible encouragement of waste tourism [10], and the increased complexity involved in designing and implementing a fee structure based on the generation of unsorted waste [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 the consumer using an individual container to deposit waste, where the capacity of the container depends on the weekly amount of waste that is deposited, and where the tariff can be applied depending on the volume or weight of the waste. The containers have a unique identifier that allows the quantity deposited to be recorded, and so 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 of waste they put in is identified according to volume or weight, and they are charged for the undifferentiated waste. The variable tariff is calculated according to the amount of undifferentiated waste deposited. In the third model, consumers have access to a system of pre-paid sacks. 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, focussed 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 aid in contextualising and explaining 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 provided by VITRUS *Ambiente*, a municipal company responsible for urban waste management, public sanitation, environmental monitoring, and the management 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's accession 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 target for its implementation, i.e., 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 implemented for the first time in 2016 by the municipality of Guimarães. Since then, this system has been implemented in other Portuguese municipalities, initially using a preliminary study for its implementation and a subsequent analysis.

Case study description

In this study, in order to assess the impact of using the PAYT waste management system, the municipality of Guimarães, located in the north of Portugal and considered to be 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 the manufacturing industry has a high weight in its economic activity, with particular relevance to 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.

The interest in adopting the new PAYT waste management paradigm in the HCG arose due to the implementation of a pilot project, whose results 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 comes after the success achieved in 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, i.e., door-to-door and through deep containers. 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 type of user, where the tariff is 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 was treated and analysed using the 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 estimation of avoided CO_2 emissions was performed, based on observed variations in the quantities of waste collected for recycling and applying 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 the implementation of 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 the increased experience with the system. Third, an estimation of avoided CO_2 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 tonnes, representing approximately 87% of total annual waste generation (943 tonnes). By contrast, separately collected waste amounted to only 122 tonnes, 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, corresponding to the initial implementation phase of the PAYT system, a marked shift in the structure of waste collection was observed. It should be noted, however, that the system only became operational in April 2016. Therefore, the data presented refer exclusively to the period between April and December. Notwithstanding this limitation, the results indicate a

reduction in the relative share of undifferentiated waste, which totalled 538 tonnes, corresponding to approximately 66.5% of total waste generation during the analysed period (809.26 tonnes). Conversely, separately collected waste increased to 270 tonnes, 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 tonnes, representing approximately 66.7% of total annual generation (941.46 tonnes), while separately collected waste reached 313.32 tonnes, accounting for approximately 33.3% of the total. 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.

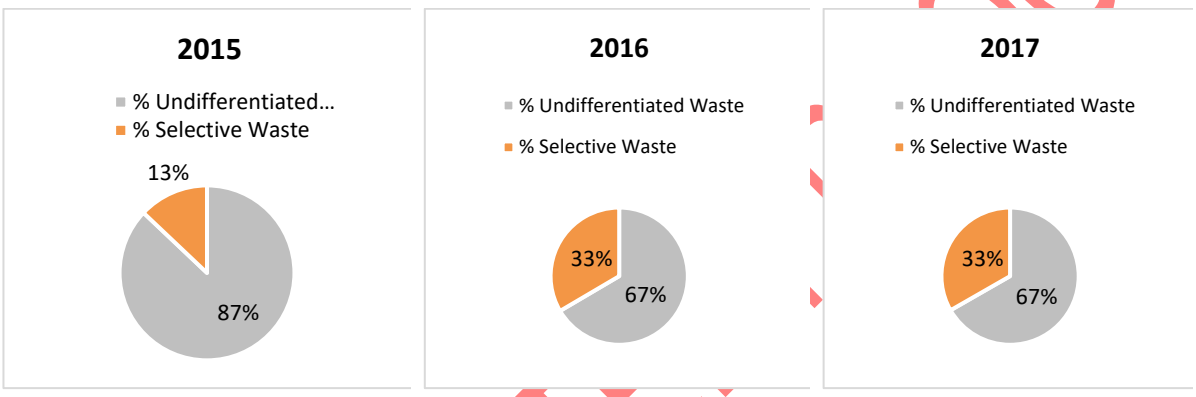

Figure 1. Percentage of solid waste collected in 2015, 2016 and 2017.

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 tonnes, decreasing to 538 tonnes in 2016 and to 628.14 tonnes 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 tonnes, suggesting a significant shift in users' disposal practices and increased participation in waste separation.

With regard to glass, a substantial increase was observed over the study period. In 2015, 67 tonnes were collected, rising to 147.72 tonnes in 2016 and to 174.44 tonnes 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 tonnes in 2015 to 68.54 tonnes in 2016 and to 84.68 tonnes 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 tonnes were collected, increasing to 54.30 tonnes in 2016 and remaining at comparable levels in 2017 (54.14 tonnes). 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 selectively collected waste. 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 the data on the tonnes of municipal solid waste (MSW) collected in the PAYT area for 2023 and its comparison with previous years. These figures come from the service sheets filled in 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 the collection of selective waste was 47 per cent, while undifferentiated collection accounted for 53 per cent. It should be noted that

selective collection means the collection of paper/cardboard, packaging, glass and bio-waste (organic waste). By 2023, the collection of undifferentiated waste will account for only 17 per cent and selective collection 83 per cent.

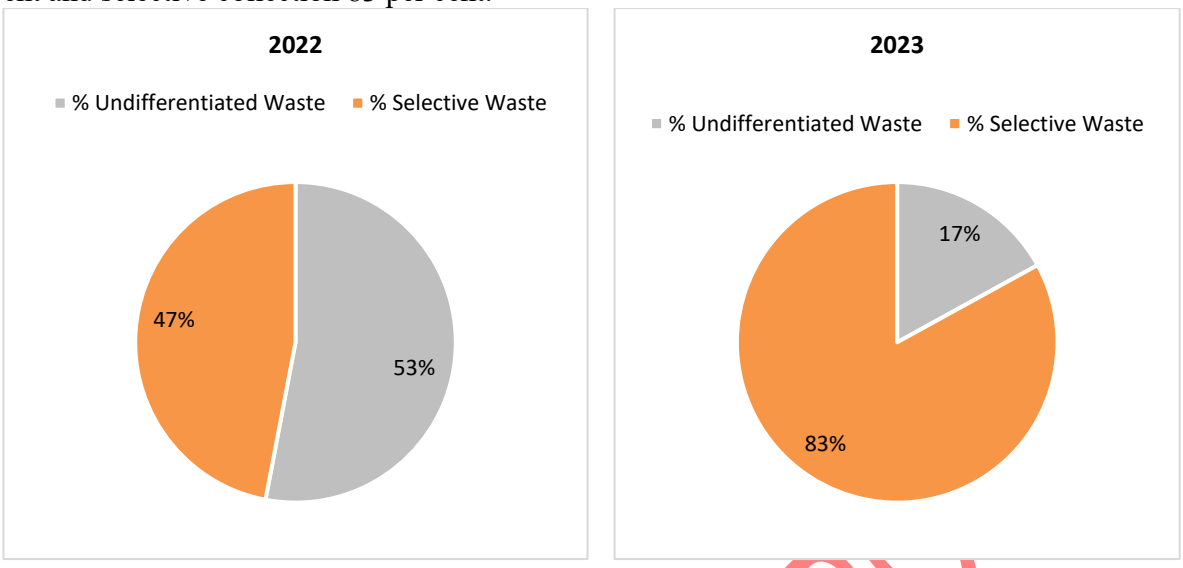

Figure 3. Percentage of solid waste collected in 2022 and 2023.

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

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

Undifferentiated waste. During 2023, a total of 539.24 tonnes of undifferentiated waste was collected, with a monthly average of 44.94 tonnes. Looking at the data in Figure 4 on the collection of undifferentiated waste, the month with the highest waste production was January (131.12 tonnes) and the month with the lowest collection was April (7.18 tonnes).

Throughout 2023, it can be seen that the number of tonnes collected in January was an exception, since in the remaining months the number of tonnes collected was always less than half of that collected in the first month of the year. Apart from January, there are only three months that exceed 40 tonnes collected each month: February, when 64.08 tonnes were collected, June, when 57.04 tonnes were collected, and December, when 44 tonnes were collected; the remaining eight months always have less than 40 tonnes collected. January is a month in which a large amount of undifferentiated waste is produced, since this month there is an abnormal production of waste due to the end-of-year festivities in which the population does not separate their waste as properly and waste that is recycled ends up in the undifferentiated waste. 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, which shows that the population is more committed to these circular economy projects, which benefit the environment and users. The average number of tonnes dropped significantly over the three years under analysis. In 2021, an average of 193 tonnes of undifferentiated waste was collected per month; in 2022, the monthly average was 173 tonnes, and the biggest difference, with a very positive impact, was in 2023, when only 45 tonnes were collected on average per month.

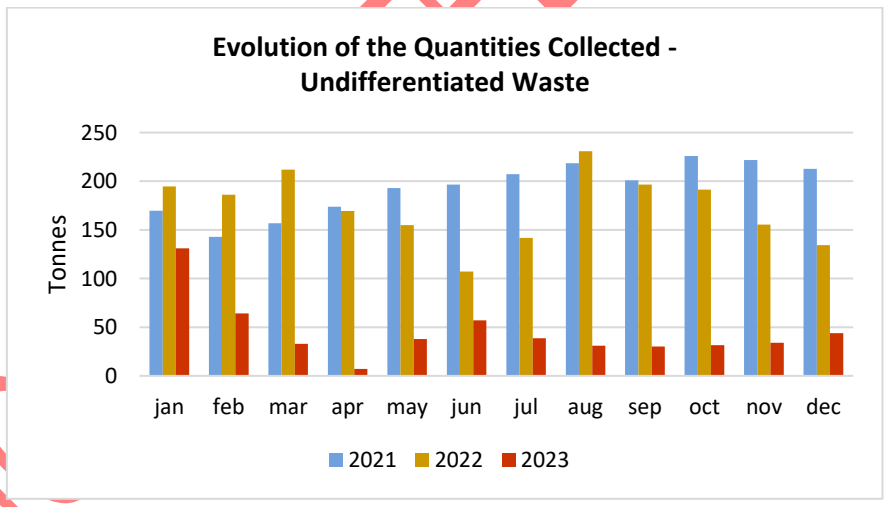

Figure 5. Evolution of the Quantities Collected (Undifferentiated Solid Waste).

Glass waste. Analysing the glass fraction, there was a total of 322.50 tonnes of glass collected in 2023, with a monthly average of 26.88 tonnes. Figure 6 shows that there are three months that stand out with 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 tonnes).

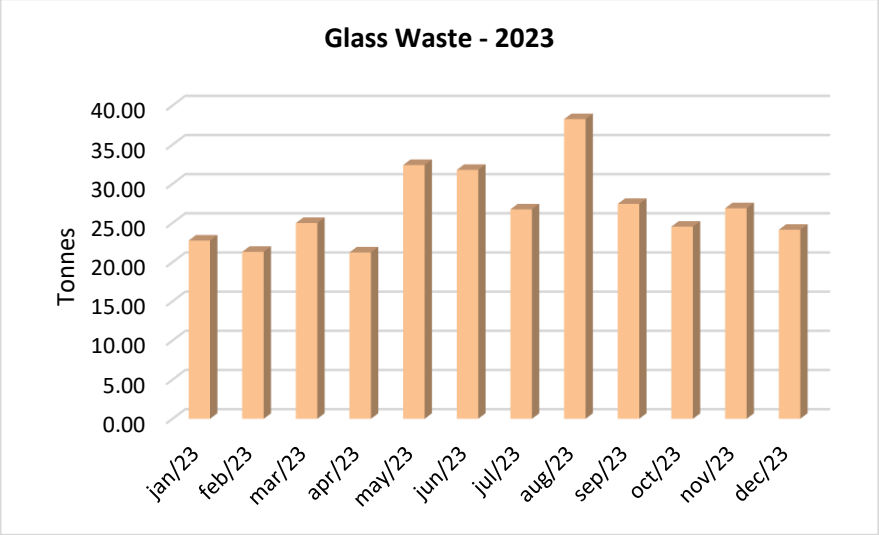

Figure 6. Selective collection of glass in the PAYT area in 2023.

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 from month to month, with August being the month in which the most tonnes of glass are collected. The months in which the greatest amount of glass waste was collected in 2023 compared to the previous two years were February, May, June, September and November.

In 2021, an average of 25 tonnes was collected per month, in 2022 the monthly average was 26 tonnes, and in 2023 the monthly average was 27 tonnes. From year to year, there has only been an increase of one tonne 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 to be set up was 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 confusion like paper/cardboard and plastic.

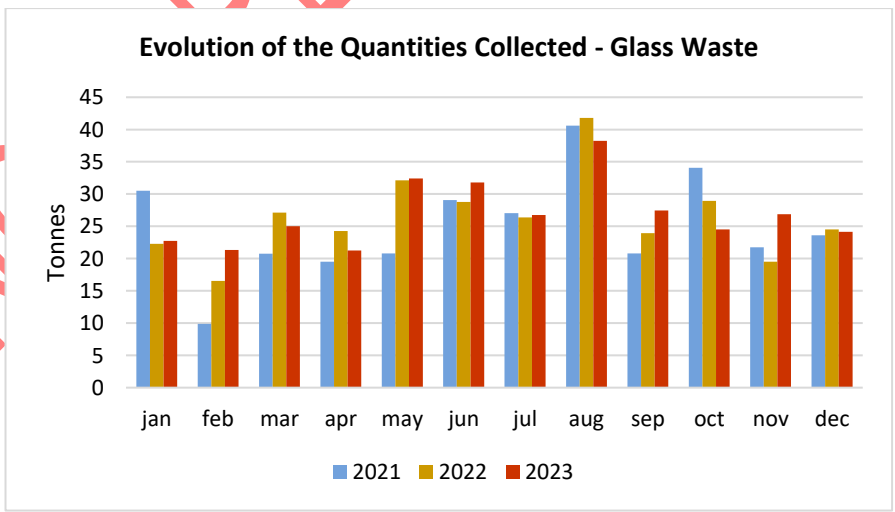

Figure 7. Evolution of the Quantities Collected (Glass waste).

Paper/cardboard waste. Throughout 2023, a total of 531.58 tonnes of paper/cardboard were collected, with a monthly average of 44.30 tonnes. The months that stand out for having a higher number of tonnes 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 the collection of selective paper/cardboard waste in Figure 8, the month with the highest waste production was December (52.06 tonnes) and the month with the lowest collection was February (37.46 tonnes).

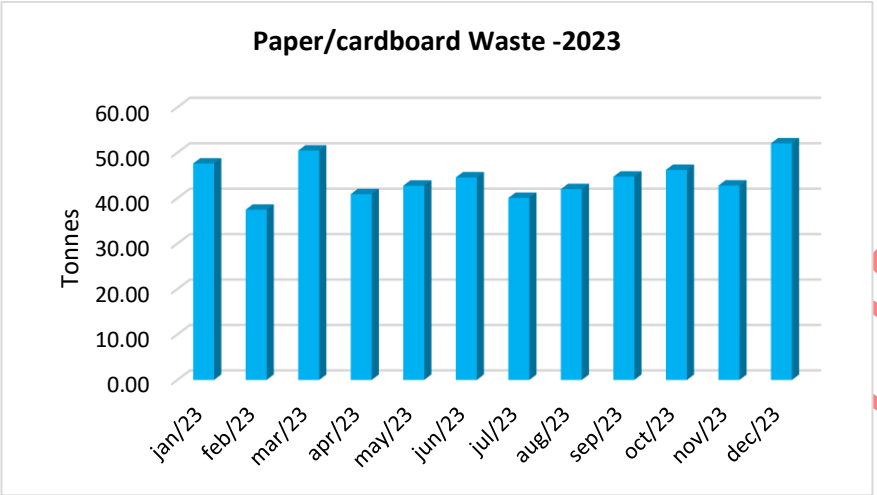

Figure 8. Selective Collection of Paper/Cardboard in the PAYT area in 2023.

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, with the exception of April, July and November. In 2021, a monthly average of 38 tonnes was collected, in 2022, the monthly average was 42 tonnes, and in 2023, with a higher average, which is a good indicator, an average of 44 tonnes was collected monthly.

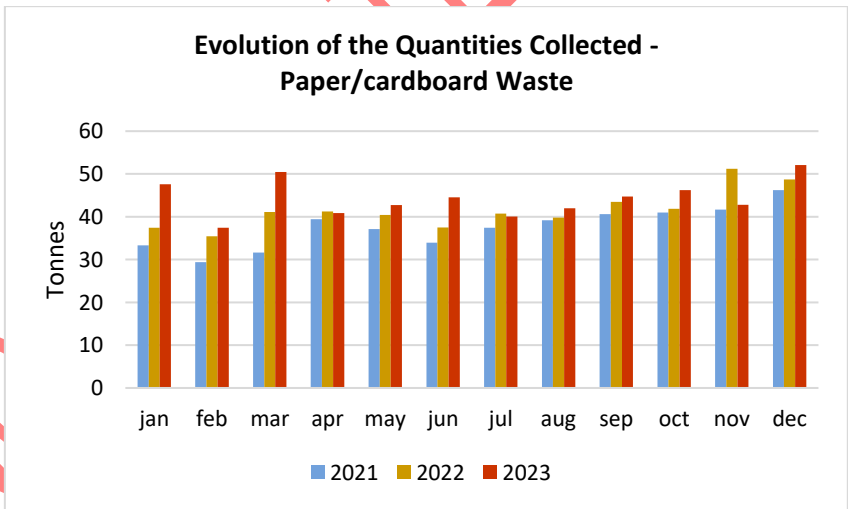

Figure 9. Evolution of the Quantities Collected (Paper/Cardboard waste).

Plastic waste. Looking at plastic waste, in 2023 there was a total of 233.20 tonnes collected, with a monthly average of 19.43 tonnes. Looking at the data on the collection of selective plastic waste in Figure 10, the month with the highest waste production was May, which stood out from the other months (29.16 tonnes), while the month with the lowest collection was February (14.88 tonnes). The months of January (20 tonnes), May (29.16 tonnes), August (19.46 tonnes), October (20 tonnes) and November (21.24 tonnes) had amounts equal to or greater than the monthly average of tonnes of this waste collected. May saw the highest number of tonnes collected, although the transition from April to May saw an increase in all selective collections, with plastic seeing a very significant increase. The justification for this figure cannot only be the increase in waste production from one month to the next, but can also be explained by the fact that plastic

containers were placed at the University of Minho, on the Azurém campus, as part of the Deucalion supercomputer project. These containers were collected in May, which greatly inflated the number of tonnes 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.

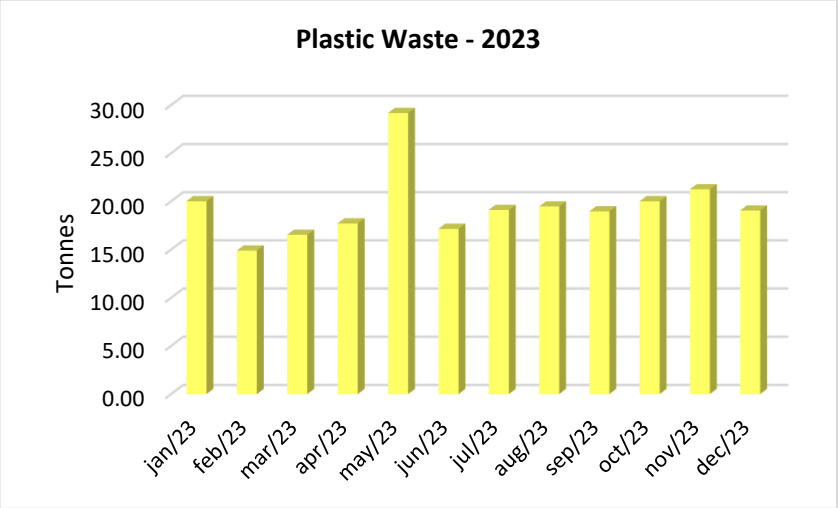

Figure 10. Selective collection of plastic in the PAYT area in 2023.

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

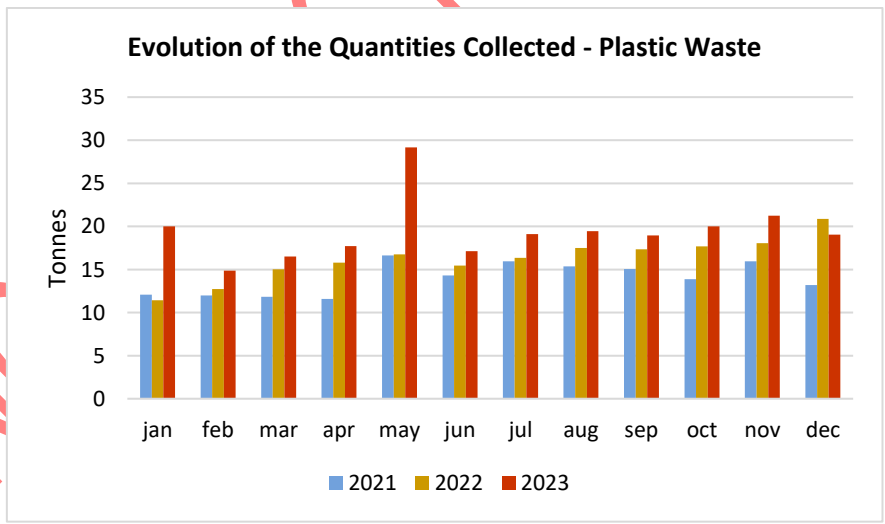

Figure 11. Evolution of quantities collected (Plastic waste).

Organic waste. Throughout 2023, a total of 1,455.28 tonnes of organic waste was collected, with a monthly average of 121.27 tonnes. Analysing the data on the selective collection of organic waste (Figure 12), the month with the highest waste production was October (152.76 tonnes) and the month with the lowest collection was July (93.90 tonnes). 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 bins for organic waste. This is a behaviour that 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 the festivities that take place at the end of the month, and consequently food waste increases, which is reflected in the increase in weighing in December and January.

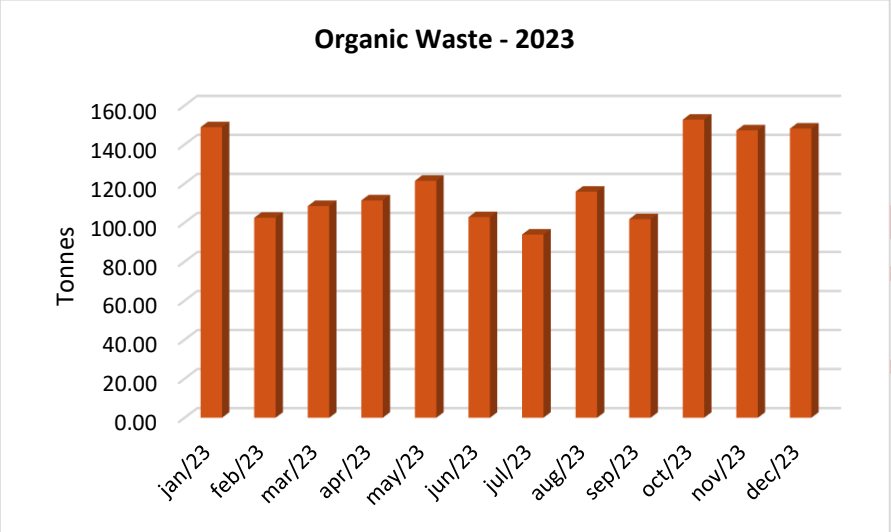

Figure 12. Selective Collection of Organics in the PAYT area in 2023.

As data on the collection of organic waste only began in January 2022, Figure 13 shows the evolution of the collection of this type of waste from that date until December 2023. In 2022, the monthly average of tonnes of organic waste collected in the PAYT area was 77 tonnes, and in 2023, an average of 121 tonnes was collected monthly. The monthly average of tonnes collected in 2022 in the PAYT area was calculated considering 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.

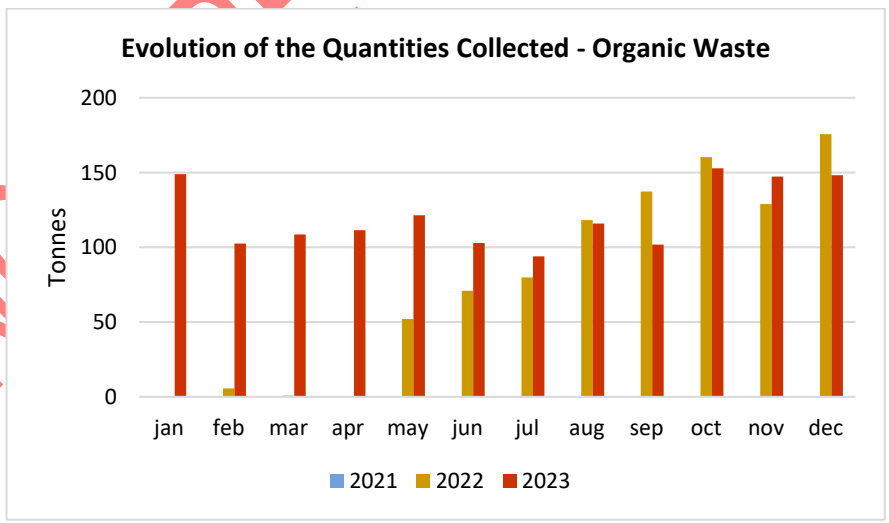

Figure 13. Evolution of quantities collected (organic waste).

The collection of organic waste has only been in place for 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, in contrast to analysing the evolution of the quantities collected for the other waste, there should be a variation in values, and the indicators should not be so positive. However, these results were to some extent to be expected given that this is

a new selective collection and that the population sometimes shows some resistance to joining new projects.

Avoided CO_2 emissions

To complement the analysis of the impacts associated with the implementation of the PAYT system, an indicative estimation of avoided CO_2 emissions was undertaken, based on the changes observed 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 Equation 1:

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

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 (tCO_2e per tonne), associated with the treatment or recovery of that waste fraction.

Initially, a comparison was performed between 2015, corresponding to the period prior to the implementation of the PAYT system, and 2017, representing the first full year of system operation. The results indicate a substantial reduction in undifferentiated waste, with a decrease of approximately 192.86 tonnes, accompanied by a marked increase in selectively collected fractions, namely: +107.44 tonnes of glass, +51.68 tonnes of paper and cardboard, and +32.14 tonnes 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 tonnes of CO_2 equivalent 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 the years 2021 and 2023, 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 tonnes, accompanied by increases in the principal selectively collected fractions: +24.12 tonnes of glass, +80.62 tonnes of paper and cardboard, and +65.40 tonnes of plastic. In addition, this period is characterised by the introduction and substantial growth of the biowaste fraction, which reached 1,455.28 tonnes in 2023, representing a relevant additional component in waste recovery. Based on these variations, an overall reduction of approximately 1,367 tonnes of CO_2 equivalent 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 a positive effect in terms of emission reductions, the more recent phase (2021–2023) exhibits a considerably greater impact. This 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.

The choice of method comes from the user, i.e., the user chooses whether to pay via the PAYT bag purchase system (Method A) or by production estimate, via a tariff set by default (Method B). In 2022, 207 requests to change method (from method B to method A) were registered, while in

2023, 559 requests were registered. 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 percentage associated with the number of DU and NDU, with DU accounting for 62 per cent of users and NDU for 38 per cent.

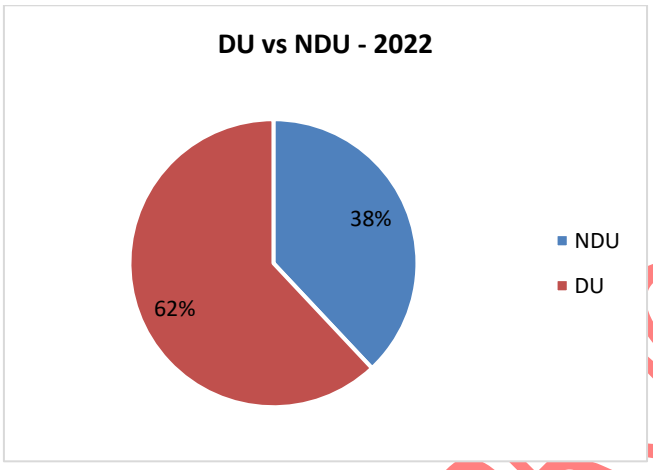

Figure 14. Percentage of DU vs. NDU (2022) in method A.

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

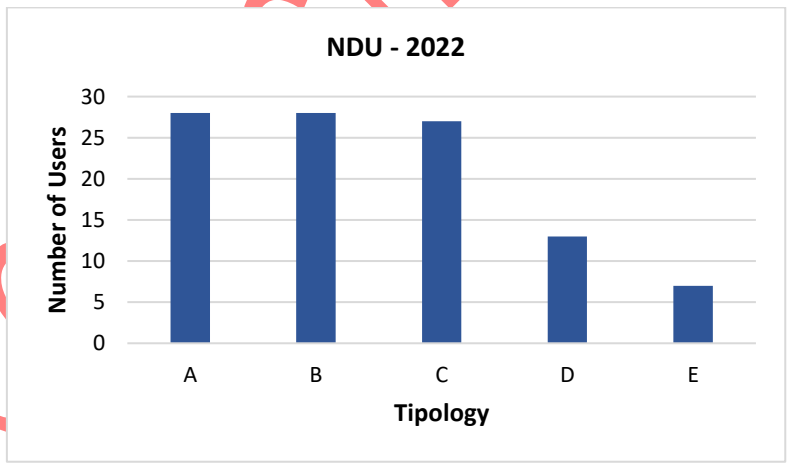

Figure 15. Number of NDU 2022 in method A by typology.

Comparing 2022 with 2023, it is possible to see a significant increase in the number of users of method A, due to the growing number of requests to change the method. It can be seen that in 2022, only 273 users were assigned to the bag purchasing method and that in 2023, there was an increase to 627 users. DU users account for 84 per cent of users, while NDU users account for 16 per cent, as can be seen in Figure 16.

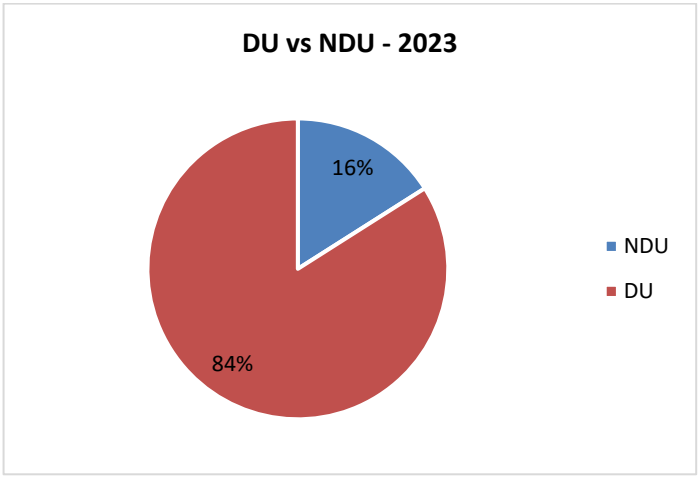

Figure 16. Percentage of DU vs. NDU (2023) in method A.

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

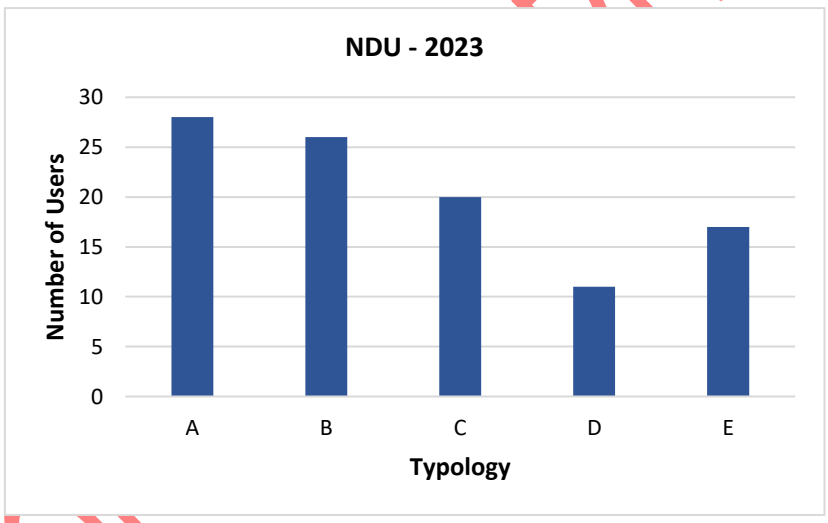

Figure 17. Number of NDU 2023 in method A by typology.

By way of conclusion, it can be seen that this significant increase is essentially due to the increase in DUs, as it is this type of user that has seen the greatest growth. The number of NDU users has remained constant. The fact that a user is included in method A implies the purchase of bags. 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 enhancing the degree of source separation of recyclable waste, the system contributes to greater 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 recyclable waste by households, which substantially constrains the overall effectiveness of the recycling process.

The results obtained put also in evidence the necessity of fostering 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 PAYT widespread adoption, emphasising the need of 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, in a study conducted in Grenoble, France, [15] reported higher levels of receptiveness among younger residents, individuals with above-median income, and those holding at least a master's degree. In contrast, based on a study in Beijing, China, [23] found that acceptance of the PAYT system was greater among older residents and residents with lower educational attainment. Accordingly, these authors emphasized 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 must be addressed by local decision-makers 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 in order 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 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 the reduction of landfill dependency by promoting alternative waste management strategies aimed at minimising final waste disposal and reducing CO2 emissions. Socially and economically, the implementation of the PAYT system influences behavioural change among residents while also generating economic benefits. This system introduces a more equitable model, wherein users are charged based on the actual volume of waste they produce, rather than on water consumption, thereby encouraging waste reduction and fostering greater accountability in waste generation.

This study has several limitations. An important one is the fact that it is mainly a descriptive and exploratory study, focussed on analysing the quantity of waste collected in the municipality of Guimarães after implementing a pilot project related to a PAYT system. Therefore, the conclusions drawn from the results obtained should be interpreted with caution. More research is needed to fully understand the reasons for the success of implementing that system. Another limitation is the fact that, although a longitudinal study was undertaken, data was collected for only three years. Thus, to have a more robust analysis and to perceive whether an effective behavioural change has actually occurred, a study should be performed for 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 the willingness of residents to participate. Therefore, as future research, it is suggested conducting a study 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 the willingness of residents in a municipality to adopt a PAYT-type waste management system and what factors 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.

REFERENCES

[1] Y. A. Hajam, R. Kumar, e A. Kumar, «Environmental waste management strategies and vermi transformation for sustainable development», *Environmental Challenges*, vol. 13, p. 100747, dez. 2023, doi: 10.1016/j.envc.2023.100747.

[2] C. Velis, «Is 'waste' an obsolete concept for circular economy, innovation and engineering?», *Waste Manag Res*, vol. 43, n.º 7, pp. 981–983, jul. 2025, doi: 10.1177/0734242X251346224.

[3] E. O. Atofarati, V. O. Adogbeji, e C. C. Enweremadu, «Sustainable smart waste management solutions for rapidly urbanizing African Cities», *Utilities Policy*, vol. 95, p. 101961, ago. 2025, doi: 10.1016/j.jup.2025.101961.

[4] V. Prieto-Sandoval, C. Jaca, e M. Ormazabal, «Towards a consensus on the circular economy», *Journal of Cleaner Production*, vol. 179, pp. 605–615, abr. 2018, doi: 10.1016/j.jclepro.2017.12.224.

[5] K. N. Esbeih, V. Molina-Moreno, P. Núñez-Cacho, e B. Silva-Santos, «Transition to the Circular Economy in the Fashion Industry: The Case of the Inditex Family Business», *Sustainability*, vol. 13, n.º 18, p. 10202, set. 2021, doi: 10.3390/su131810202.

[6] B. Thomas e F. McDougall, «International expert group on life cycle assessment for integrated waste management», *Journal of Cleaner Production*, vol. 13, n.º 3, pp. 321–326, fev. 2005, doi: 10.1016/j.jclepro.2004.02.021.

[7] L. Keßler, S. A. Matlin, e K. Kümmerer, «The contribution of material circularity to sustainability—Recycling and reuse of textiles», *Current Opinion in Green and Sustainable Chemistry*, vol. 32, p. 100535, dez. 2021, doi: 10.1016/j.cogsc.2021.100535.
[8] A. P. Provin, A. R. D. A. Dutra, I. C. A. De Sousa E Silva Gouveia, e E. A. L. V. Cubas, «Circular economy for fashion industry: Use of waste from the food industry for the production of biotextiles», *Technological Forecasting and Social Change*, vol. 169, p. 120858, ago. 2021, doi: 10.1016/j.techfore.2021.120858.
[9] D. Mandarić, A. Hunjet, e D. Vuković, «The Impact of Fashion Brand Sustainability on Consumer Purchasing Decisions», *JRFM*, vol. 15, n.º 4, p. 176, abr. 2022, doi: 10.3390/jrfm15040176.
[10] G. Romano e L. Masserini, «Pay-as-you-throw tariff and sustainable urban waste management: An empirical analysis of relevant effects», *Journal of Environmental Management*, vol. 347, p. 119211, dez. 2023, doi: 10.1016/j.jenvman.2023.119211.
[11] European Environment Agency, *From data to decisions*. em EEA Briefing. LU: Publications Office, 2024. doi: 10.2800/6444220.
[12] Z. Musova, H. Musa, J. Drugdova, G. Lazaroiu, e J. Alayasa, «Consumer Attitudes Towards New Circular Models in the Fashion Industry», *JOC*, vol. 13, n.º 3, pp. 111–128, set. 2021, doi: 10.7441/joc.2021.03.07.
[13] L. Jäämaa e R. Kaipia, «The first mile problem in the circular economy supply chains – Collecting recyclable textiles from consumers», *Waste Management*, vol. 141, pp. 173–182, mar. 2022, doi: 10.1016/j.wasman.2022.01.012.
[14] C. Emmanouil, K. Papadopoulou, I. Papamichael, e A. A. Zorpas, «Pay-as-You-Throw (PAYT) for Municipal Solid Waste Management in Greece: On Public Opinion and Acceptance», *Sustainability*, vol. 14, n.º 22, p. 15429, nov. 2022, doi: 10.3390/su142215429.
[15] L. Ghazaryan, C. Faure, J. Schleich, e M. M. Birau, «Transition from a fixed fee to a pay-as-you-throw waste tariff scheme: Effectiveness of environmental and accountability appeals», *Journal of Environmental Management*, vol. 385, p. 125603, jun. 2025, doi: 10.1016/j.jenvman.2025.125603.
[16] J. Reichenbach, «Status and prospects of pay-as-you-throw in Europe – A review of pilot research and implementation studies», *Waste Management*, vol. 28, n.º 12, pp. 2809–2814, dez. 2008, doi: 10.1016/j.wasman.2008.07.008.
[17] S.-E. Chachami-Chalioti, C. Emmanouil, D. Latinopoulos, e A. Kungolos, «Circular Economy Aspects of the New National Solid Waste Management Plan and Citizens' Engagement in Northern Greece», *Circ.Econ.Sust.*, vol. 4, n.º 3, pp. 2011–2030, set. 2024, doi: 10.1007/s43615-024-00374-6.
[18] B. Bilitewski, «From traditional to modern fee systems», *Waste Management*, vol. 28, n.º 12, pp. 2760–2766, dez. 2008, doi: 10.1016/j.wasman.2008.03.032.
[19] M. Hadzi-Nikolova *et al.*, «Biowaste Management and Circular Economy: Usage of Pay as you Throw System and Autonomous Composting Units in Municipality of Probishtip», *Circ.Econ.Sust.*, vol. 2, n.º 4, pp. 1283–1300, dez. 2022, doi: 10.1007/s43615-021-00122-0.
[20] L. Alves, S. Silva, e I. Soares, «Waste management in insular areas: A Pay-As-You-Throw system in Funchal», *Energy Reports*, vol. 6, pp. 31–36, dez. 2020, doi: 10.1016/j.egyr.2020.10.024.
[21] L. Rizzo e R. Secomandi, «Pay as You Throw Threshold Tariff: Evidence on the Incentive to Recycle», *The B.E. Journal of Economic Analysis & Policy*, vol. 24, n.º 2, pp. 361–395, abr. 2024, doi: 10.1515/bejeap-2022-0448.
[22] A. Ukkonen e O. Sahimaa, «Weight-based pay-as-you-throw pricing model: Encouraging sorting in households through waste fees», *Waste Management*, vol. 135, pp. 372–380, nov. 2021, doi: 10.1016/j.wasman.2021.09.011.
[23] C. Zhang, B. Ma, e Q. Du, «Public acceptability and its determinants of unit pricing for municipal solid waste disposal: Evidence from a household survey in Beijing», *Journal of Environmental Management*, vol. 346, p. 118966, nov. 2023, doi: 10.1016/j.jenvman.2023.118966.
[24] J. Adu, M. F. Owusu, E. Martin-Yeboah, L. A. Pino Gavidia, e S. Gyamfi, «A discussion of some controversies in mixed methods research for emerging researchers», *Methodological Innovations*, vol. 15, n.º 3, pp. 321–330, nov. 2022, doi: 10.1177/20597991221123398.
[25] M. García-Valiñas, F. Arbués, e R. Balado-Naves, «Assessing environmental profiles: An analysis of water consumption and waste recycling habits», *Journal of Environmental Management*, vol. 348, p. 119247, dez. 2023, doi: 10.1016/j.jenvman.2023.119247.

[26] D. Freitas, «Implementação do sistema Pay As You Throw - PAYT no centro histórico de Guimarães e zona envolvente», Dissertação de Mestrado, Universidade Fernando Pessoa, Guimaraes, Portugal, 2013. [Em linha]. Disponível em: http://hdl.handle.net/10284/4155

[27] A. W. Larsen e T. Astrup, «CO2 emission factors for waste incineration: Influence from source separation of recyclable materials», *Waste Management*, vol. 31, n.º 7, pp. 1597–1605, jul. 2011, doi: 10.1016/j.wasman.2011.03.001.