“Evaluating the efficiency of public expenditure in municipal waste collection: A comparative study of Portuguese municipalities”

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EVALUATING THE EFFICIENCY OF PUBLIC EXPENDITURE IN MUNICIPAL WASTE COLLECTION: A COMPARATIVE STUDY OF PORTUGUESE MUNICIPALITIES

Abstract

Effective waste management is fundamental to sustainable development and the well-being of societies. This study focuses on the financial efficiency of urban waste collection in Portuguese municipalities, with the aim to analyze the effects of the allocation of public resources in the waste management sector. The main objective is to analyze the relationship between public spending and waste collection over a five-year period. Through the application of the classic data envelopment analysis model (DEA), the study seeks to observe the existence of benchmarking patterns, identify possible inefficiencies, and determine opportunities for improvement in urban waste management and collection practices. The results suggest substantial variations in waste collection efficiency between municipalities and a positive correlation between public spending and the volume of waste collected. The results emphasize the need for a strategic allocation of financial resources in order to promote sustainable waste management practices. The paper highlights the importance of municipalities reassessing their strategies for allocating financial resources to ensure a better balance between funding and efficiency in the use of resources. The conclusions offer valuable practical implications for defining strategies and managing municipal waste collection services in Portugal and other countries with similar contexts.

Keywords environmental sustainability, financial efficiency, funding efficiency, municipal waste, public spending, Portuguese municipalities, resource allocation, waste management

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INTRODUCTION

The efficiency of municipal waste collection is an essential area of research due to its environmental, economic, and social implications. Waste management is one of the crucial aspects of society, since the growing amount of waste produced and the need to adopt sustainable management practices are increasingly essential for reducing environmental effects.

Governments need to optimize the allocation of financial resources to the growing collection of urban waste. Defining a balance between environmental needs and budgetary constraints requires academia to have a greater understanding of the dynamics of how public resources are allocated. It is crucial to address the relationship between public spending and waste collection results. By elucidating this relationship, the results can contribute to the perception of waste collection efficiency levels and assist in the public decision-making process through the implementation of public policies that promote the practice of more efficient collection processes.

This topic is pertinent given that Portuguese municipalities face significant challenges in waste management. Examining possible relationships between public spending and the levels of municipal waste collected can provide information to improve management systems and the quality of life of residents.

1. LITERATURE REVIEW AND HYPOTHESES

Efficiency in the collection of municipal urban waste is currently one of the most relevant areas of research for the development of the theoretical field of territorial management and public administration (Rodrigues, 2016). Observing efficiency involves assessing the processes, methods, and practices used by municipalities to collect municipal waste (Phillips & Thorne, 2013). This helps one identify benchmarking practices and opportunities to optimize the financial resources allocated to public services (Simões & Marques, 2009).

For financial theory, one of the main metrics for analyzing the efficiency of public spending is the relationship between the financial resources allocated and the results obtained by public services (Aquino, 2011). Thus, analyzing the efficiency of public services, regardless of their substance and purpose, includes the costs associated with the remuneration of employees, the equipment assigned to the service, as well as the time and costs associated with carrying out operations (Rocha, 2020). In a broader analysis, it is also possible to consider the relationship between the quality of the public service provided and the level of public spending carried out for the purposes of pursuing the financial public interest (Inês, 2014).

Fonseca (2016) emphasizes the importance of comparing private and public management models and operational structuring processes in the municipal waste collection sector, particularly in terms of efficiency. The techniques adopted to measure efficiency levels alternate between parametric (stochastic frontier model) and non-parametric (DEA model) systems. However, according to Zhu (2001), due to the sensitivity of the results, the analysis can significantly affect the reliability of the efficiency assessment. Accordingly, the efficiency of municipalities in municipal waste collection should be analyzed from the perspective of the super-efficiency model approach. The theory allows the most efficient municipalities to be identified among the most efficient (Bruno & Erbetta, 2013).

Rogge and Jaeger (2012), Afonso and Fernandes (2005), and Sala-Garrido et al. (2022) suggested using data envelopment analysis to assess the performance of municipal waste collection by analyzing the relationship between public expenditure and resource productivity. Public expenditure serves as an input, while the quantities of waste collected and treated reflect the efficiency of the system. The strength of the model lies in its ability to measure the economic efficiency of various types of waste in relation to operational activities (Camanho et al., 2024). To illustrate the usefulness of DEA, Camanho et al. (2024) assessed the efficiency of 293 Flemish municipalities, concluding that only 0.17% of average revenues were dedicated to waste collection, treatment, and disposal, based on municipal accounts and statistics.

Huang et al. (2011) applied the DEA methodology to 307 municipalities in Taiwan. The efficiency model for municipal waste collection services was based on five performance criteria (completeness, applicability, ability to measure results, similarity, and distinctiveness), each of which was assigned a set of weights. The study conclude that the DEA model allows each municipality to assess its performance and, likewise, to compare the multiple levels of efficiency between local authorities. The best results, in terms of collection, are from reference models (Lofti et al., 2016).

In China, urban waste collection constitutes 57.4% of total fixed asset investment (Zhou et al., 2022). Their study across 27 Chinese cities reveals notable efficiency, with six cities employing benchmark management models. Similarly, Storto (2021) evaluated waste collection efficiency in Italy from 2010 to 2019, observing modest improvements attributable to enhanced technical efficiency and technology allocation. Nonetheless, Storto (2021) underscores the challenge posed by escalating per capita waste generation in Italy.

The surge in urban waste volume poses a pressing challenge for municipal services, necessitating efficient waste management solutions (Custódio,

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2021). Doussoulin and Colther (2022) stress the criticality of evaluating waste management efficiency for municipal performance analysis and policy formulation. Their study of 280 Chilean municipalities from 2014 to 2019 identifies significant asymmetries in waste collection systems, highlighting rural areas as particularly inefficient. However, Dotti et al. (2024) assert that efficiency disparages persist across territories, underscoring the need for nuanced approaches to address waste management challenges comprehensively.

In Ukraine, Shkarupa et al. (2020) analyzed waste collection system efficiencies, linking them to financing strategies. They advocate for higher-quality investments to improve efficiency, particularly advocating for increased financial allocation for constructing waste sorting stations in Sumy. Deineko et al. (2019) highlight issues in Ukrainian waste management efficiency, attributing them to inadequate legislation, limited public investment, and ineffective policies.

Currently, due to the high levels of urban waste production, municipalities are experiencing considerable difficulties in collecting and treating waste due to the successive increases in public spending associated with the service (Pharino, 2017). To tackle this issue, Sehlabi and McKay (2016) examined the efficiency levels of urban waste management in the city of Johannesburg (South Africa) using composting units. They concluded that the social returns (increased employment opportunities and quality of life for the city's inhabitants) are not sufficient to cover the financial outlay.

In South Africa, Worku (2016) investigated waste management in Tshwane, evaluating compliance with ISO standards. Findings revealed inefficiencies attributed to non-compliance with municipal regulations. Camões and Silva (2023), along with McAllister (2015), underscored the negative effects of ineffective waste collection on local communities, advocating for selective collection to enhance logistical efficiency. Additionally, Bodjongo et al. (2023) emphasized the need for policy adaptations to promote cost-effective waste management alongside efforts to ensure legal adherence.

In Palestine, Sabri et al. (2013) conducted a thorough analysis of waste collection efficiency, emphasizing its cost-benefit aspect and financial sustainability. Municipal waste collection services were found to consume a substantial portion, ranging from 3% to 32%, of municipal budgets, posing financial challenges. Their study underscored the discrepancy between revenue and expenditure in providing public services. Additionally, they compared the efficiency of waste collection between the public and private sectors, noting the latter superior performance and cost-effectiveness. Tavares (2019) and Pheakdey et al. (2022) further delved into resource allocation dynamics, arguing that inefficiencies were not inherent to ownership structures but stemmed from the intersection of political interests and economic rationality.

This study analyzes the efficiency of urban waste collection in Portuguese municipalities between 2018 and 2022, looking at the level of correlation between public spending on collection and the amount of waste collected. The paper aims to assess the efficiency of Portuguese municipal waste management in order to estimate the effectiveness of strategies for allocating public financial resources to the urban services provided.

To this end, the following hypotheses were established:

H1: Municipal spending on municipal waste collection services is not related to the tons collected with an efficiency equal to 1 ($e\lambda = 0$).

H2: Municipal expenses associated with municipal waste collection services have some level of relationship with the tons collected of efficiency equal to 1 ($0 > e\lambda < 1$).

H3: Municipal spending on municipal waste collection services has a perfect relationship with the tons collected with an efficiency equal to 1 ($e\lambda = 1$).

2. METHODS

This analysis is based on a case study. Statistical data from 308 Portuguese municipalities were analyzed relating to public spending (on waste collection) and the quantities of waste collected (tons declared by municipal services) from 2018

to 2022. The expenditure and tonnage databases were obtained from the official websites of Banco de Portugal and PORDATA.

The statistical information from the municipalities was distributed in a matrix and arranged into decision-making centers (DMUs), inputs (public spending), and outputs (undifferentiated, selective, and total collection). For each type of collection, the weight of the inputs (actual public expenditure) and their relationship with the outputs (tons of waste) were assessed.

The paper applies the non-parametric DEA methodology, in which a direct relationship between inputs and outputs is not defined. The efficiency of public expenditure (inputs) in relation to the total amount of municipal waste collected is assessed using an index (Paço & Pérez, 2013), in which the municipality is more efficient when it is able to collect the greatest number of tons with the lowest level of financial resources allocated to carry out the public service (Carvalho & Rizzo, 1994).

Waste collection efficiency varies between 0 (inefficient) and 1 (efficient) and is measured by the distance between the inefficient DMU and the most efficient DMU (Jahanshahloo & Afzalinejad, 2006). The methodology selected for analyzing the results was the input-oriented model, where efficiency is described using the following expression (Vincová, 2005):

$$Efficiency = \frac{\sum_{r=1}^{s} U_r Y_r}{\sum_{i=1}^{m} V_i X_i}, \quad (1)$$

where U_r = weight of tons of municipal waste collected; Y_r = the level of tons of municipal waste; V_i = weight of actual public expenditure associated with municipal urban waste collection; X_i = the level of effective public expenditure; s = number of sectors related to the tons of municipal waste collected; and m = number of sectors related to actual public expenditure.

The procedure adopted assesses the efficiency of the allocation of public financial resources (actual public expenditure) in each of the Portuguese municipalities. The numerator ($\sum^{s}_{r=1} U_r Y_r$) measures the total amount of tons of municipal waste (outputs) generated by the municipalities, weighted by the weights associated with each sector of municipal waste collected. The denominator ($\sum^{m}_{i=1} V_i X_i$) evaluates the total amount of actual public spending by municipalities, weighted by the weights associated with each sector of public spending by municipalities.

The efficiency of the allocation of public resources in municipal waste collection is obtained by dividing the tons of municipal waste collected by the total weighted efficiency of actual public spending on municipal waste collection. The results obtained provide a practical perspective on the level of efficiency in the allocation of public spending on the collection of waste produced in each of the political and geographical areas, bearing in mind the respective limitations and theoretical reservations of the DEA model (Lins et al., 2007).

The efficiency levels of each municipality were measured using Excel software. The DEA model was selected as a tool for measuring municipal urban waste collection due to its high degree of flexibility in defining the input-output matrix. In addition, it allows for selecting the model's orientation, since the preference of the analysis is to maintain levels of effective public spending (inputs) and increase the efficiency of municipal urban waste collection (outputs).

3. RESULTS

The results provide a new perspective on the levels of efficiency between the ratio of actual public expenditure in each of the 308 municipalities and the amount of municipal waste collected each year. Table 1 and Figure 1 show municipalities that are the most and least efficient in allocating public spending on municipal waste collection by district and autonomous region.

In 2018, the most efficient municipalities in allocating public expenditure to municipal waste collection were Aveiro (Aveiro), Beja (Beja), Braga (Braga), Carrazeda de Ansiães (Bragança), Covilhã (Castelo Branco), Coimbra (Coimbra), Montemor-o-Velho (Évora), Loulé (Faro), Trancoso (Guarda), Nazaré (Leiria), Torres Vedras (Lisboa), Elvas (Portalegre), Paredes (Porto),

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Almeirim (Santarém), Setúbal (Setúbal), Viana do Castelo (Viana do Castelo), Vila Real (Vila Real), and Moimenta da Beira (Viseu).

In relation to the autonomous regions of Madeira and the Açores, the most efficient municipalities in allocating public spending to waste collection in 2018 were Câmara de Lobos and Vila da Praia da Vitória, respectively.

The results suggest that the least efficient municipalities in allocating expenditure to urban waste collection were Arouca, with 21.4771% (Aveiro), Barrancos, with 21.1125% (Beja), Terras de Bouro, with 6.4252% (Braga), Vimioso, with 24.2997% (Bragança), Oleiros, with 0.7383% (Castelo Branco), Góis, with 10.9535% (Coimbra), Mourão with a total of 23.4488% (Évora), Monchique, with 7.5099% (Faro), Aguiar da Beira, with 30.8681% (Guarda), Batalha, with 2.7262% (Leiria), Sobral de Monte Agraço, with 23.6018% (Lisboa), Castelo de Vide, with 23.2472% (Portalegre), Póvoa de Varzim, with 22.4481% (Porto), Sardoal, with 3.8935% (Santarém), Sesimbra, with 34.3105% (Setúbal), Melgaço, with 17.9853% (Viana do Castelo), Ribeira de Pena, with 15.4012% (Vila Real), and Castro Daire, with 32.3908% (Viseu).

With regard to the autonomous regions, Table 1 and Figure 1 show that the least efficient municipalities were Porto Moniz, with 21.2599% (Madeira), and Vila do Porto, with 9.7021% (Açores).

For 2019, the estimated results show that the most efficient municipalities in allocating public spending to the municipal waste collection are the cities of Aveiro (Aveiro), Ferreira do Alentejo (Beja), Braga (Braga), Carrazeda de Ansiães (Bragança), Covilhã (Castelo Branco), Coimbra (Coimbra), Montemor-o-Velho (Évora), Faro (Faro), Trancoso (Guarda), Nazaré (Leiria), Torres Vedras (Lisboa), Marvão (Portalegre), Paredes (Porto), Almeirim (Santarém), Montijo (Setúbal), Viana do Castelo (Viana do Castelo), Peso da Régua (Vila Real), and Moimenta da Beira (Viseu).

In the autonomous regions, the results suggest that the most efficient cities in the collection of selective and undifferentiated waste were Câmara de Lobos (Madeira) and Calheta (Açores).

Conversely, the least efficient municipalities in allocating public spending on municipal waste collection in 2019 were Arouca, with 21.9194% (Aveiro), Barrancos, with 21.9126% (Beja), Terras de Bouro, with 6.4089% (Braga), Vimioso, with 23.7161% (Bragança), Oleiros, with 0.7469% (Castelo Branco), Góis, with 11.3223% (Coimbra), Mourão, with 24.0607% (Évora), Monchique, with 7.3983% (Faro), Almeida, with 32.8340% (Guarda), Batalha, with 2.7823% (Leiria), Sobral de Monte Agraço, with 23.1530% (Lisboa), Castelo de Vide, with 18.8897% (Portalegre), Póvoa de Varzim, with 23.1130% (Porto), Sardoal, with 4.9242% (Santarém), Sesimbra, with 33.6365% (Setúbal), Melgaço, with 18.4188% (Viana do Castelo), Ribeira de Pena, with 18.2672% (Vila Real,) and Castro Daire, with 31.0605% (Viseu).

As far as the autonomous regions are concerned, the results show that the least efficient cities in the allocation of public expenditure for the management of municipal waste collection were Porto Moniz, with 21.6058% (Madeira), and Vila do Porto, with 11.7833% (Açores).

In 2020, the estimated data showed that the most efficient municipalities in terms of the waste collection werr Aveiro (Aveiro), Beja (Beja), Braga (Braga), Carrazeda de Ansiães (Bragança), Covilhã (Castelo Branco), Coimbra (Coimbra), Montemor-o-Velho (Évora), Portimão (Faro), Trancoso (Guarda), Nazaré (Leiria), Torres Vedras (Lisboa), Elvas (Portalegre), Paredes (Porto), Almerim (Santarém), Montijo (Setúbal), Viana do Castelo (Viana do Castelo), Peso da Régua (Vila Real), and Tarouca (Viseu).

As for the autonomous regions, the most efficient municipalities in allocating public funds to the waste collection service were Câmara de Lobos (Madeira) and Calheta (Açores).

On the other hand, in 2020, the data show that the municipalities with the least efficient financial management of municipal waste collection were Arouca, with 22.4632% (Aveiro), Barrancos, with 24.2641% (Beja), Terras de Bouro, with 6.2482% (Braga), Vimioso, with 24.1152% (Bragança), Oleiros, with 0.7813% (Castelo Branco), Góis, with 12.0736% (Coimbra), Mourão with 25.3157% (Évora), Monchique, with 7.2247% (Faro),

Almeida, with 33.7909% (Guarda), Batalha, with 2.9798% (Leiria), Sobral de Monte Agraço, with 21.5544% (Lisboa), Castelo de Vide, with 18.9907% (Portalegre), Póvoa de Varzim, with 22.4548% (Porto), Sardoal, with 5.0521% (Santarém), Alcácer do Sal, with 36.9167% (Setúbal), Melgaço, with 17.2671% (Viana do Castelo), Ribeira de Pena, with 17.0384% (Vila Real), and Penedono, with 43.3458% (Viseu).

In the autonomous regions, the estimated data show that the least efficient municipalities when it comes to allocating public resources to municipal waste collection were Porto Moniz, with 18.8914% (Madeira), and Vila do Porto, with 10.5876% (Açores).

In 2021, the data suggest that the most efficient cities in terms of the relationship between public spending and the level of tons of municipal waste collected were Vagos (Aveiro), Beja (Beja), Braga (Beja), Macedo de Cavaleiros (Braga), Covilhã (Castelo Branco), Vila Nova de Poiares (Coimbra), Montemor-o-Velho (Évora), Faro (Faro), Trancoso (Guarda), Nazaré (Leiria), Loures (Lisboa), Elvas (Portalegre), Vila Nova de Gaia (Porto), Almeirim (Santarém), Setúbal (Setúbal), Viana do Castelo (Viana do Castelo), Peso da Régua (Vila Real), and Moimenta da Beira (Viseu).

In terms of the autonomous regions, the municipalities of Santana (Madeira) and Vila da Praia da Vitória (Açores) had the highest levels of efficiency in the ratio between public spending and municipal waste collection.

Conversely, in 2021, the least efficient municipalities in allocating public resources to municipal waste collection were Espinho, with 24.7968% (Aveiro), Barrancos, with 21.2283% (Beja), Terras de Bouro, with 1.1284% (Braga), Miranda do Bouro, with 17.3420% (Bragança), Oleiros, with 2.1649% (Castelo Branco), Penela, with 7.5004% (Coimbra), Mourão, with 29.8561% (Évora), Monchique, with 8.5189% (Faro), Almeida, with 27.8406% (Guarda), Porto de Mós, with 7.3101% (Leiria), Sobral de Monte Agraço, with 18.6977% (Lisboa), Nisa, with 7.9740% (Portalegre), Póvoa de Varzim, with 12.1803% (Porto), Alcanena, with 0.0001% (Santarém), Barreiro, with 33.3210% (Setúbal), Melgaço, with 5.7165% (Viana do Castelo), Ribeira de Pena, with 15.8052% (Vila Real), and Vouzela, with 27.6355% (Viseu).

With regard to the autonomous regions, the data suggest that the least efficient municipalities in terms of the ratio between public spending and municipal waste collection were São Vicente, with 25.0122% (Madeira) and Lajes do Porto, with 9.5928% (Açores).

For 2022, the results suggest that the most efficient cities in allocating public financial resources to carry out the municipal waste collection service were Aveiro (Aveiro), Ferreira do Alentejo (Beja), Braga (Braga), Carrazeda de Ansiães (Bragança), Covilhã (Castelo Branco), Vila Nova de Poiares (Coimbra), Alandroal (Évora), Faro (Faro), Figueira de Castelo Rodrigo (Guarda), Nazaré (Leiria), Cadaval (Lisboa), Marvão (Portalegre), Porto (Porto), Tomar (Santarém), Setúbal (Setúbal), Viana do Castelo (Viana do Castelo), Peso da Régua (Vila Real), and São João da Pesqueira (Viseu).

As for the autonomous regions in 2022, the results suggest that the most efficient cities in allocating public financial resources to waste collection were Ribeira Brava (Madeira) and Calheta (Açores).

On the other hand, for the same period, the municipalities with the lowest levels of efficiency in the allocation of public financial resources to waste collection were Arouca, with 39.5851% (Aveiro), Barrancos, with 14.0387% (Beja), Vieira do Minho, with 14.4380% (Braga), Vimioso, with 41.5717% (Bragança), Sertã, with 2.7749% (Castelo Branco), Pampilhosa da Serra, with 3.7827% (Coimbra), Mourão, with 21.7920% (Évora), Monchique, with 8.4365% (Faro), Gouveia, with 45.7969% (Guarda), Castanheira de Pêra, with 9.9761% (Leiria), Sobral do Monte Agraço, with 27.9219% (Lisboa), Nisa, with 25.2641% (Portalegre), Baião, with 13.3522% (Porto), Sardoal, with 1.5286% (Santarém), Sesimbra, with 23.0450% (Setúbal), Paredes de Coura, with 7.2962% (Viana do Castelo), Ribeira de Pena, with 44.2841% (Vila Real), and Sernancelhe, with 35.2483% (Viseu).

As far as the autonomous regions are concerned, the results show that the least efficient municipalities in terms of the ratio between public spending and ton of waste collected were Porto Moniz, with 12.3370% (Madeira), and Lajes do Pico, with 4.6685% (Açores).

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Figure 1. The more (green) and less (red) efficient municipalities by districts and autonomous regions, 2018–2022

Table 1 shows that the results on the efficiency of municipal waste collection in Portugal by district reject hypotheses 1 ($e\lambda = 0$), 2 ($0 > e\lambda < 1$), and 3 ($e\lambda = 1$). The data suggest that there is some relationship between public spending and the quantities of municipal waste collected, i.e., the level of spending has contributed in some way to the efficiency of municipal waste collection (selective and undifferentiated) in Portuguese municipalities.

The results of the average efficiency of public spending on municipal waste collection are irregular (Table 1), which allows the hypotheses defined to be validated and rejected simultaneously.

In 2018, hypothesis 1 was rejected, hypothesis 2 was confirmed in 251 municipalities, and hypothesis 3 was validated in 57 municipalities. In 2019, hypothesis 1 was rejected, hypothesis 2 was confirmed in 244 municipalities, and hypothesis 3 was accepted in 64 municipalities. For 2020, hypothesis 2 was accepted in 251 municipalities and hypothesis 3 in 57 municipalities; hypothesis 1 was rejected. As for 2021, hypothesis 1 was rejected, hypothesis 2 was confirmed in 250 municipalities, and hypothesis 3 was confirmed in 58 municipalities. Finally, in 2022, hypothesis 1 was rejected, hypothesis 2 was confirmed in 244 municipalities, and hypothesis 3 was validated in 64 municipalities.

Table 1. Results by districts and autonomous regions (2018–2022)

Efficiency	Districts and Autonomous Regions	2018		2019		2020		2021		2022	
		Municipalities	Results	Municipalities	Results	Municipalities	Results	Municipalities	Results	Municipalities	Results
More efficient	Aveiro	Aveiro	100.000%	Aveiro	100.000%	Aveiro	100.000%	Vagos	100.000%	Aveiro	100.000%
	Beja	Beja	100.000%	Ferreira do Alentejo	100.000%	Beja	100.000%	Beja	100.000%	Ferreira do Alentejo	100.000%
	Braga	Braga	100.000%	Braga	100.000%	Braga	100.000%	Braga	100.000%	Braga	100.000%
	Bragança	Carrazeda de Ansiães	100.000%	Carrazeda de Ansiães	100.000%	Carrazeda de Ansiães	100.000%	Macedo de Cavaleiros	100.000%	Carrazeda de Ansiães	100.000%
	Castelo Branco	Covilhã	100.000%	Covilhã	100.000%	Covilhã	100.000%	Covilhã	100.000%	Covilhã	100.000%
	Coimbra	Coimbra	100.000%	Coimbra	100.000%	Coimbra	100.000%	Vila Nova de Poiares	100.000%	Vila Nova de Poiares	100.000%
	Évora	Montemor-o-Velho	100.000%	Montemor-o-Velho	100.000%	Montemor-o-Velho	100.000%	Montemor-o-Velho	100.000%	Alandroal	100.000%
	Faro	Loulé	100.000%	Faro	100.000%	Portimão	100.000%	Faro	100.000%	Faro	100.000%
	Guarda	Trancoso	100.000%	Trancoso	100.000%	Trancoso	100.000%	Trancoso	100.000%	Castelo Rodrigo	100.000%
	Leiria	Nazaré	100.000%	Nazaré	100.000%	Nazaré	100.000%	Nazaré	100.000%	Nazaré	100.000%
	Lisboa	Torres Vedras	100.000%	Torres Vedras	100.000%	Torres Vedras	100.000%	Loures	100.000%	Cadaval	100.000%
	Portalegre	Elvas	100.000%	Marvão	100.000%	Elvas	100.000%	Elvas	100.000%	Marvão	100.000%
	Porto	Paredes	100.000%	Paredes	100.000%	Paredes	100.000%	Vila Nova de Gaia	100.000%	Porto	100.000%
	Santarém	Almeirim	100.000%	Almeirim	100.000%	Almeirim	100.000%	Almeirim	100.000%	Tomar	100.000%
	Setúbal	Setúbal	100.000%	Montijo	100.000%	Montijo	100.000%	Setúbal	100.000%	Setúbal	100.000%
	Viana do Castelo	Viana do Castelo	100.000%	Viana do Castelo	100.000%	Viana do Castelo	100.000%	Viana do Castelo	100.000%	Viana do Castelo	100.000%
	Vila Real	Vila Real	100.000%	Peso da Régua	100.000%	Peso da Régua	100.000%	Peso da Régua	100.000%	Peso da Régua	100.000%
	Viseu	Moimenta da Beira	100.000%	Moimenta da Beira	100.000%	Tarouca	100.000%	Moimenta da Beira	100.000%	São João Pesqueira	100.000%
	A.R. of Madeira	Câmara de Lobos	100.000%	Câmara de Lobos	100.000%	Câmara de Lobos	100.000%	Santana	100.000%	Ribeira Brava	100.000%
	A.R. of Açores	Vila Praia da Vitória	100.000%	Calheta [R.A.A.]	100.000%	Calheta [R.A.A.]	100.000%	Vila Praia da Vitória	100.000%	Calheta [R.A.A.]	100.000%

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Table 1 (cont.). Results by districts and autonomous regions (2018–2022)

Efficiency	Districts and Autonomous Regions	2018		2019		2020		2021		2022	
		Municipalities	Results	Municipalities	Results	Municipalities	Results	Municipalities	Results	Municipalities	Results
Less efficient	Aveiro	Arouca	21.4771%	Arouca	21.9194%	Arouca	22.4632%	Espinho	24.7968%	Arouca	39.5851%
	Beja	Barrancos	21.1125%	Barrancos	21.9126%	Barrancos	24.2641%	Barrancos	21.2283%	Barrancos	14.0387%
	Braga	Terras de Bouro	6.4252%	Terras de Bouro	6.4089%	Terras de Bouro	6.2482%	Terras de Bouro	1.1284%	Vieira do Minho	14.4380%
	Bragança	Vimioso	24.2997%	Vimioso	23.7161%	Vimioso	24.1152%	Miranda do Douro	17.3420%	Vimioso	41.5717%
	Castelo Branco	Oleiros	0.7383%	Oleiros	0.7469%	Oleiros	0.7813%	Oleiros	2.1649%	Sertã	2.7749%
	Coimbra	Góis	10.9535%	Góis	11.3223%	Góis	12.0736%	Penela	7.5004%	Pampilhosa da Serra	3.7827%
	Évora	Mourão	23.4488%	Mourão	24.0607%	Mourão	25.3157%	Mourão	29.8561%	Mourão	21.7920%
	Faro	Monchique	7.5099%	Monchique	7.3983%	Monchique	7.2247%	Monchique	8.5189%	Monchique	8.4365%
	Guarda	Aguiar da Beira	30.8681%	Almeida	32.8340%	Almeida	33.7909%	Almeida	27.8406%	Gouveia	45.7969%
	Leiria	Batalha	2.7262%	Batalha	2.7823%	Batalha	2.9798%	Porto de Mós	7.3101%	Castanheira de Pêra	9.9761%
	Lisboa	Sobral Monte Agraço	23.6018%	Sobral Monte Agraço	23.1530%	Sobral Monte Agraço	21.5544%	Sobral Monte Agraço	18.6977%	Sobral Monte Agraço	27.9219%
	Portalegre	Castelo de Vide	23.2472%	Castelo de Vide	18.8897%	Castelo de Vide	18.9907%	Nisa	7.9740%	Nisa	25.2641%
	Porto	Póvoa de Varzim	22.4481%	Póvoa de Varzim	23.1130%	Póvoa de Varzim	22.4548%	Póvoa de Varzim	12.1803%	Baião	13.3522%
	Santarém	Sardoal	3.8935%	Sardoal	4.9242%	Sardoal	5.0521%	Alcanena	0.0001%	Sardoal	1.5286%
	Setúbal	Sesimbra	34.3105%	Sesimbra	33.6365%	Alcácer do Sal	36.9167%	Barreiro	33.3210%	Sesimbra	23.0450%
	Viana do Castelo	Melgaço	17.9853%	Melgaço	18.4188%	Melgaço	17.2671%	Melgaço	5.7165%	Paredes de Coura	7.2962%
	Vila Real	Ribeira de Pena	15.4012%	Ribeira de Pena	18.2672%	Ribeira de Pena	17.0384%	Ribeira de Pena	15.8052%	Ribeira de Pena	44.2841%
	Viseu	Castro Daire	32.3908%	Castro Daire	31.0605%	Castro Daire	43.3458%	Vouzela	27.6355%	Sernancelhe	35.2483%
	A.R. of Madeira	Porto Moniz	21.2599%	Porto Moniz	21.6058%	Porto Moniz	18.8914%	São Vicente	25.0122%	Porto Moniz	12.3370%
	A.R. of Açores	Vila do Porto	9.7021%	Vila do Porto	11.7833%	Vila do Porto	10.5875%	Lajes do Pico	9.5928%	Lajes do Pico	4.8180%

4. DISCUSSION

Analyzing the efficiency of public spending on municipal waste collection services is fundamental for understanding the efficiency levels of municipal collection services and, on the other hand, for defining the best strategies for allocating financial resources to ensure that municipal waste collection services are provided in an appropriate and sustainable manner (Ferreira et al., 2020). The efficiency of public spending plays a decisive role in the effectiveness and sustainability of municipal waste collection services. In Portugal, by prioritizing the adoption of more efficient and transparent financial management (Magalhães et al., 2023), municipalities can and should define operational strategies together with citizens in order to increase the quality of public services (Humphreys, 1998), promote more responsible environmental practices (Keles et al., 2023), and meet the needs and expectations of citizens (Meirinhos et al., 2022).

The results corroborate the need for municipalities to increase the efficiency of public expenditure allocated to waste collection and for public decision-makers to adopt high-performance management models with low levels of expenditure (Bevilacqua et al., 2010). The data are in line with the conclusions of the aforementioned studies.

The results stress the need for Portuguese municipalities to re-evaluate decisions on the allocation of public financial resources in terms of expenditure on municipal urban waste collection services. Due to inefficiencies and the emergence of a private sector, Nepal et al. (2022) state that municipalities have been forced to reform their waste management strategies. On the other hand, the results suggest a correlation between the efficiency of public spending and the quality and effectiveness of waste collection services. In other words, municipalities with higher levels of efficiency in municipal waste collection tend to have better levels of management of available resources (Volsuuri et al., 2023).

The study defends the relevance of measuring the various levels of performance of municipalities in the collection of urban waste, especially in terms of the expenditure allocated to the pursuit of the public interest. In line with the conclusions of Rogge and Jaeger (2012) and Afonso and Fernandes (2005), the levels of efficiency of municipalities in allocating public expenditure to waste collection and, consequently, the level of productivity of public resources are necessary to consider. On the other hand, Camanho et al. (2024) note advantages to selecting and applying the DEA model to assess the efficiency of public service expenditure, especially in terms of operational activities. However, the results obtained do not support the conclusions, as the efficiency of Portuguese municipalities is clearly higher than that of Flemish municipalities. This is mainly due to the low levels of public revenue allocated to urban waste collection services in Belgium.

As with Huang et al.'s (2011) study on Taiwan's 307 municipalities, it is also possible to compare the different levels of efficiency of local authorities in Portugal, which allows decision-makers to assess operational performance. In fact, as the theory goes, the best results correspond to reference models in the operational management of municipalities (benchmarking), whether in Taiwan or Portugal.

At the level of Chinese municipalities, Zhou et al. (2022) estimated an efficiency in the allocation of financial resources for waste collection of 57.40%. Yang et al. (2018) found an efficiency level of between 57.5% and 99.2%. In Portugal, the average efficiency levels were 52.76% (2018), 53.25% (2019), 52.79% (2020), 46.45% (2021), and 52.35% (2022). The results, unlike those of Chinese municipalities, indicate that Portuguese municipalities are less efficient. Storto (2021) explains a different situation, in which the level of efficiency of Italian municipalities has been growing over the years due to gains in operational productivity. In the case of Portugal, it is possible to see the same trend of increasing efficiency levels in the allocation of public financial resources to the collection of municipal waste over the period in question.

Contrary to Doussoulin and Colther's (2022) conclusions for the Chilean context, in which urban municipalities tend to be more efficient, in the Portuguese case, the results suggest that territorial location is not a determining factor for the most efficient municipalities. In this sense, efficiency lev-

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els are not evenly distributed across the territory. However, the study validates the conclusions of Shkarupa et al. (2020), i.e., the higher the level of funding for public urban waste collection services, the higher the efficiency levels of the municipalities. In the case of Portugal, the conclusions are significantly valid since the data indicate that the most efficient Portuguese municipalities are those with the highest levels of funding for collection services. Supporting Deineko et al. (2019), one of the main problems with the efficiency of the management of waste collection services in Portugal is mainly due to the low levels of investment made by municipalities. According to Sabri et al. (2013), waste collection services cost between 3% and 32% of municipal budgets, while in the Portuguese case, they take up between 0.2% and 35.3% of municipal budgets.

If the level of funding is a relevant factor in defining the level of efficiency (Volsuuri et al., 2023), this study agrees with Tavares (2019) and Pheakdey et al. (2022). The inefficiency of municipalities is not only due to a lack of funding but also from the overlapping of political interests with the operational rationality of the urban waste collection activity. The results also support Ma et al. (2023) considering the importance of social awareness in achieving better levels of service efficiency. The adoption of efficient waste collection models is fundamental to guaranteeing the healthiness of the urban environment, preventing pollution, and promoting public health (Hoang et al., 2024). The existence of high levels of efficiency in the collection of urban waste, in fact, contributes to reducing the costs related to waste treatment and relieving pressure on public resources.

As for the hypotheses, the data mostly point to the validation of hypothesis 2, since the majority of municipalities do not have a technical efficiency ratio equal to 1, but rather a ratio between public spending and tons of municipal waste collected greater than 0 and less than 1.

In addition to analyzing the efficiency levels of municipal services, a pertinent question for future research is to study the effects of adopting artificial intelligence in defining possible routes, managing the various types of municipal waste, and promoting the circular economy.

CONCLUSION

The study analyzed the financial efficiency of municipal waste collection in Portugal over five years using data envelopment analysis. The aim was to provide evidence-based public policy on municipal waste collection to improve the sustainability and effectiveness of waste management.

The results suggest that the level of expenditure made has contributed in some way to the efficiency of waste collection. There is a notable disparity in levels of technical efficiency between the 308 Portuguese municipalities. The data confirm a positive correlation between realized expenditure and the quantities of municipal waste collected.

The paper shows that municipalities with higher levels of public funding tend to exhibit higher levels of efficiency in waste collection. However, efficiency is not only determined by the amount of expenditure made; it is also affected by political rationality, which tends to override economic logic.

The results suggest that Portuguese municipalities need to re-evaluate and adjust their strategies for allocating financial resources to waste collection in order to ensure a better balance between the levels of funding required and the efficient use of available resources. The analysis highlights the importance of municipalities promoting social awareness and environmental education among citizens in order to encourage active participation in achieving efficiency gains in municipal waste collection.

The findings emphasize the importance of efficiency in the operational management of municipal waste, the need to draw up more effective environmental policies, the existence of adequate levels of funding,

and the involvement of the community in the process of continuous improvement. However, this study has some limitations. It only covers a five-year period, which may not be enough time to observe all the variations and trends over time. It is solely focused on Portuguese municipalities, which may limit the application and generalization of the results to other geographical contexts. Finally, efficiency is based on the relationship between public spending and the amount of waste collected and disregards other factors that may also affect efficiency.

Regardless of the identified limitations, the study presents a perspective on the efficiency of the allocation of public resources to municipal urban waste collection services, highlighting the need to continue improving the performance of the public service.

AUTHOR CONTRIBUTIONS

Conceptualization: Ricardo de Moraes e Soares.
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Investigation: Ricardo de Moraes e Soares.
Methodology: Ricardo de Moraes e Soares.
Resources: Ricardo de Moraes e Soares.
Software: Ricardo de Moraes e Soares.
Supervision: Ricardo de Moraes e Soares.
Visualization: Ricardo de Moraes e Soares.
Writing – original draft: Ricardo de Moraes e Soares.
Writing – review & editing: Ricardo de Moraes e Soares.

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