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Evaluation of the impact of separate collection and recycling on the efficiency of waste management services in Spanish municipalities

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Abstract

The collection of municipal solid waste (MSW) is a public service with impact mainly on the environment and public health. The objective of this article is to evaluate the impact of separate collection and recycling of MSW on the efficiency of the provision of MSW services by municipalities. In doing so, it was analyzed and compared the efficiency and eco-efficiency of waste collection services in 85 municipalities in Spain. The non-parametric technique of Data Envelopment Analysis (DEA) was used as a methodology, with a radial model assuming variable returns to scale technology and) input orientation. Among the most relevant results, is the finding that a percentage of 46% of the municipalities performs waste management separately from their origin, that is, they are eco-efficient.

Keywords: Waste management, Performance, Efficiency, Eco-efficiency, Data Envelopment Analysis, Municipal solid waste

1. Introduction

In recent years, international policy has focused on the protection of the environment and, especially, on the sustainable management of waste [1]. In 1992, the United Nations Conference on Environment and Development recommended more careful management of waste and recycling habits. This is due to the global increase in the generation of solid waste caused mainly by the increase in the density of the urban population, as a result of several factors such as population and economy growth (Daskalopoulos et al., 1998). Several investigations have carried out, through the collection of data, the generation of reports, the analysis of resources associated with municipal solid waste (MSW) management) integrating environmental, economic and social issues [6].

The production of MSW is linked to the economic development of a country and has become one of the most serious problems that modern society has had to face [12]. That is why improving efficiency in the collection and disposal of waste is a subject that began to be studied in the last decade, but still little explored, due to the complexity of its composition, the cost involved and the increase in environmental concerns [17]. Some researches such as those by [3], [5], [18] estimate the performance in the management of MSW services and analyze the variables and methods to achieve higher levels of efficiency and cost savings for the service.

From a methodological point of view, two main approaches have been used to estimate the efficiency in the provision of MSW services, namely, data envelope analysis (DEA) and stochastic frontier analysis (SFA). Recognizing that both techniques have advantages and shortcomings, most of the previous studies used DEA because it is a nonparametric approach that does not need to define a functional form for the efficient frontier.

From this perspective, the concept of eco-efficiency which is defined as the production of more goods and services, with fewer resources and with less environmental impact [11]. The prefix 'eco' represents the ecological and economic performance, including also the associated environmental variables [10]. This concept ppears as a response to the need for indicators of productivity and efficiency in clean and green production processes, which support the original affirmation of the Brundtland Report (1987) on the direct benefit of sustainable development. This concept was originally proposed by the World Council for Sustainable Development in the World Business Council for Sustainable Development WBCSD (2000) and was created as a business concept to be applied to private companies. However, it can also be used for public administrations (WBCSD 2000).

In this context, the main objective of this study is to evaluate the impact of separate collection and recycling of MSW in the performance of the provisions of MSW services by municipalities. In doing so, two synthetic indexes were estimated namely: efficiency and eco-efficiency. The first one is based on inputs and outputs whereas the second one considers both desirable and undesirable outputs. In particular, desirable outputs are the volumes of wastes such as glass, paper and plastic that is recycled and undesirable output is the unsorted waste. The empirical application carried out focused on a sample of Spanish municipalities.

The contribution of this research to the literature is integrate undesirable outputs in performance assessment of municipalities in the provision of MSW services. This approach allows to estimate the eco-efficiency that unlike the conventional assessment of efficiency integrates not only economic but also environmental variables. This issue is very relevant to support decision-making by municipalities since it provides information about the trade-off between economic and environmental performance of municipalities in MSW services provision.

2. Methodology

To investigate the performance of MSW management in Spanish municipalities, efficiency and eco-efficiency scores were calculated considering desirable outputs and undesirable outputs. In doing so, DEA method was used. It uses mathematical programming techniques to develop frontier-relating inputs and outputs [7]. DEA is a methodology based on linear programming models proposed for the first time by [4] to evaluate the efficiency relative to a series of decision-making unit (DMU). This first model is known as CCR (Charnes, Cooper, and Rhodes) and it assumes constant returns to scale technology. Later, [2] developed the model considering variable returns to scale technology called BCC.

For this study, efficiency and eco-efficiency of municipalities in MSW management was estimated using the BCC-DEA model with input orientation because the aim of the municipalities is collect and treat MSW at the lowest possible cost [13].

2.1. Estimation of efficiency scores

The methodological approach to calculate the efficiency scores of municipalities in the management of MSW based only in the total quantity of waste collected without considering selective waste collection and recycling is described. Assuming a production process in which, from an input vector $x \in \mathfrak{R}_{+}^{N}$, a vector of desirable outputs $y \in \mathfrak{R}_{+}^{M}$ results is obtained using the T technology. The set of production possibilities is defined as follows:

$$P(x) = \{(x, y) : x \; can \; produce \; y\} \tag{1}$$

The input distance function is defined as

$$D(x, y) = min_{\theta}\{\theta > 0 : x\theta \in P(x)\} \tag{2}$$

The input distance function indicates the maximum reduction of inputs for each unit (for this study the municipalities) can obtain and can still produce the same vector of desirable outputs [16]. The input-oriented distance function is interpreted in the following way: if, $D(x, y) > 1$, then the input vector, x, belongs to the interior of $P(x)$; therefore, the unit is inefficient since it can reduce the use of inputs to generate the same output vector. By contrast, if $D(x, y) = 1$, then x is located on the production frontier and the unit is efficient.

To compute efficiency scores while assuming variable returns to scale technology and input orientation, the following linear programming model was solved for each municipality [14]:

$$
\begin{aligned}
& Min\ \ \theta \\
& s.t. \\
& \sum_{j=1}^{N} \lambda_j x_{ij} \leq \theta x_{i0} && 1 \leq i \leq M \\
& \sum_{j=1}^{N} \lambda_j y_{rj} \geq y_{r0} && 1 \leq r \leq S \\
& \sum_{j=1}^{N} \lambda_j = 1 && \\
& \lambda_j \geq 0 && 1 \leq k \leq N
\end{aligned}
\tag{3}
$$

where θ indicates the efficiency of the municipality evaluated, M is the number of inputs used; S is the number of outputs generated, N is the number of DMUs analyzed, and λ_j is a set of intensity variables which represent the weighting of each analyzed municipalities j in the composition of the efficient frontier $\theta \in (0,1]$; a unit (municipalities) is efficient if its efficiency score (θ) equals unity, whereas it is inefficient if $0 \leq \theta < 1$.

2.2 Estimation of eco-efficiency scores

A DEA model to compute eco-efficiency adjusted scores, i.e., DEA research on the introduction of unclassified waste as undesirable output and recyclable waste as desirable outputs is presented subsequently. Assuming a production process where from an input $x \in \mathfrak{R}_+^N$, a vector of desirable outputs $y \in \mathfrak{R}_+^M$ and another vector of undesirable outputs $b \in \mathfrak{R}_+^H$ are obtained using the technology T. The production possibility set of desirable and undesirable outputs is defined as follows:

$$P^*(x) = \{(y,b): x\ can\ produce\ (y,b)\} \tag{4}$$

The input distance function including undesirable outputs is defined as follows:

$$D(x,y,b) = min_\theta\{\theta > 0: x\theta \ \in P^*(x)\} \tag{5}$$

Following [9], for each municipality j, the linear programing (Eq. 6) was solved to compute eco-efficiency scores including environmental variables:

$$
\begin{aligned}
& Min\ \ \theta^* \\
& s.t. \\
& \textstyle\sum_{j=1}^{N} \lambda_j x_{ij} \leq \theta^* x_{i0} && 1 \leq i \leq M \\
& \textstyle\sum_{j=1}^{N} \lambda_j y_{rj} \geq y_{r0} && 1 \leq r \leq S \\
& \textstyle\sum_{j=1}^{N} \lambda_j b_{zj} = b_{z0} && 1 \leq z \leq H \\
& \textstyle\sum_{j=1}^{N} \lambda_j = 1 && \\
& \lambda_j \geq 0 && 1 \leq k \leq N
\end{aligned} \tag{6}
$$

where θ^* indicates the eco-efficiency score of the municipalities evaluated, M is the number of inputs used; S is the number of desirable outputs generated, H is the number of undesirable outputs involved in the assessment; N is the number of municipalities analyzed, and λ_j is a set of intensity variables which represent the weighting of each analyzed municipalities j in the composition of the efficient frontier. As in Eq. (3), $\theta^* \in (0, 1]$ and a municipality is efficient if θ^* equals unity, whereas it is inefficient if $0 \leq \theta^* < 1$

3. Sample Description

The models described above were applied to calculate the efficiency and eco-efficiency of a sample of 85 Spanish municipalities. In the case of Spain, MSW collection is a local public service that must be provided by all municipalities, but no single form of service is stipulated. In this regard, the most common formulas are public management, privatization and inter-municipal cooperation [20]. For this research, the 85 municipalities evaluated provide MSW services through concessions to private companies.

Regarding the selection of variables to evaluate the performance of municipalities in MSW management, based on past research [19], several variables were involved in the analysis carried out. The selection of input and output variables to estimate efficiency and eco-efficiency scores of municipalities was also influenced by sample size (i.e., number of municipalities analysed) and the availability of data. Two variables were used as inputs namely: i) total cost of MSW management expressed in euro/year. It involves all costs incurred by the municipality to collect and dispose MSW and; ii) total number of containers which was used as a proxy to capital costs. To evaluate efficiency, a single output was considered which was the quantity of MSW collected by each municipality expressed in tons per year. In the eco-efficiency assessment, as it has been explained previously, desirable and undesirable outputs were integrated in the model. The desirable outputs are recyclable wastes which were categorized as: i) quantity of paper collected and recycled; ii) quantity of glass collected and recycled and; iii) quantity of plastic collected and recycled. These three desirable outputs were expressed in tons/year. The undesirable output which should be minimize by the municipalities is the quantity of unsorted waste expressed in tons per year (see Table 1).

A basic statistical description of the variables used to evaluate efficiency and eco-efficiency is shown on Table 2.

Table 1: Variables used as inputs and outputs to evaluate efficiency and eco-efficiency of municipalities in MSW management

Efficiency assessment	**Eco-efficiency assessment**
Inputs: i) total costs of MSW collection and disposal (€/year); ii) total number of containers	Inputs: i) total costs of MSW collection and disposal (€/year); ii) total number of containers
Output: i) quantity of MSW collected and disposed (ton/year)	Desirable outputs: i) quantity of paper collected and recycled (ton/year); ii) quantity of glass collected and recycled (ton/year); iii) quantity of plastic collected and recycled (ton/year) Undesirable output: unsorted waste (ton/year)

Table 2: Main statistical data of the sample

	Total costs (€/year)	**Containers (nr)**	**Total waste collected (ton/year)**	**Paper collected (ton/year)**	**Glass collected (ton/year)**	**Plastic collected (ton/year)**	**Unsorted waste (ton/year)**
Average	38,747.81	99.28	3,115.72	78.21	74.02	93.84	2,869.65
SD	91,005.86	175.33	6,625.27	166.28	145.38	204.12	6,125.59
Minimum	1,161.35	6.00	76.59	1.09	1.29	1.03	69.06
Maximum	689,065.09	1,150.00	45,265.12	1,202.23	970.56	1,412.18	41,680.14

A limitation in any DEA model is the number of municipalities analyzed in relation to the number of inputs and outputs. To avoid relative efficiency discrimination problems, "Cooper´s rule" must be taken into account. Accordingly, the number of units (municipalities) to be evaluated must be larger than or equal to $max\{m \; x \; s; 3\;(m+s)\}$ where m is the number of inputs and s is the number of outputs involved in the assessment [15]. In this study, 85 municipalities were evaluated while the number of inputs was two and the number of outputs (desirable and undesirable) was four. Hence, “Cooper´s rule” is meet.

4. Results and discussion

The efficiency and eco-efficiency scores were estimated for the 85 Spanish municipalities. In the Table 3 shows the main statistical features of the results. The complete sample of the Spanish municipalities illustrated that when the evaluation of the efficiency excludes the collection of waste separately (recycling), the average score was 0.75. This means that, on average, the municipalities evaluated could reduce their inputs by 25% if they were operated as efficient municipalities. In this scenario, only 16 of the 85 municipalities were efficient, which corresponds to 18.8%. In contrast, when the separate collection of MSW is integrated into the evaluation, the number of efficient municipalities approximately doubles (39 out of 85, which represents 45.8% of the sample) and the average eco-efficiency score increases to 0.92. This finding means that municipalities get better performance when the assessment integrates separate waste collection and recycling. It involves that municipalities are doing economic efforts to increase the percentage of separate waste collection and their recycled.

Table 3: Main statistics of the efficiency and eco-efficiency scores of municipalities evaluated

	Efficiency score (□)	**Efficiency score (□*)**
Average	0.75	0.92
SD	0.19	0.10
Maximum	1.00	1.00
Minimum	0.20	0.63
Percentage of efficient municipalities	18.82	45.88

Figure 1 shows the distribution of the efficiency scores of the 85 Spanish municipalities evaluated, considering only the volume of MSW collected as output. It can be seen that the percentage of inefficient municipalities is 81%. This finding means that the cost of recycling municipal solid waste for 81% of the units evaluated is still very high comparing with efficient units. This data can also be seen in the histogram of Figure 2, which shows the ranges of the efficiency scores of the municipalities, which among the efficiency indices of 0.6 and 0.8 are the majority of the municipalities, followed by the range 0.8 - 1.0.

Figure 1: Efficiency scores of the Spanish municipalities evaluated.

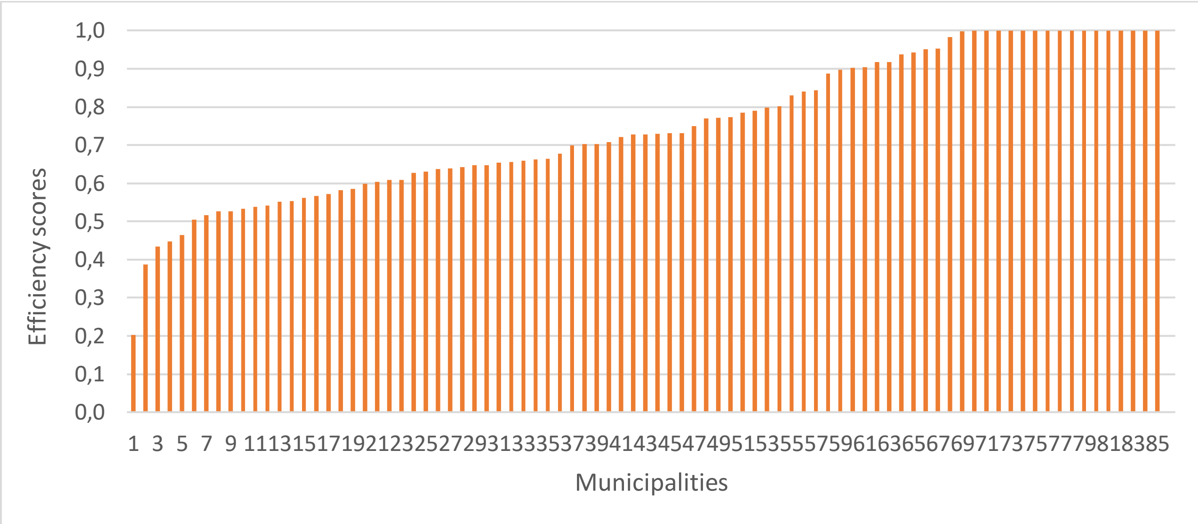
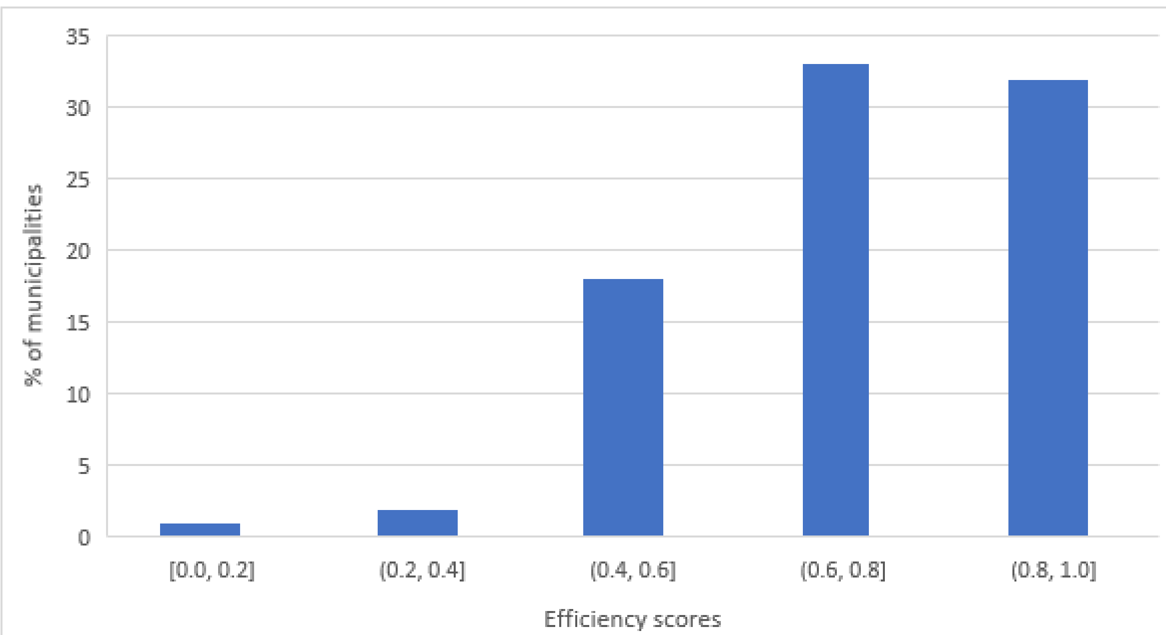


Figure 2: Histogram of efficiency scores of the Spanish municipalities evaluated



The eco-efficiency scores of the evaluated municipalities are shown in Figure 3. This graph shows that 46% of the municipalities are eco-efficient which means that more than double the total number of municipalities evaluated, they work more efficiently considering the undesirable outputs, that is, the separate collection of waste. Figure 4 shows the histogram of eco-efficiency scores illustrating that almost all municipalities (70%) present an eco-efficiency score ranged between 0.8

and 1.0. Moreover, it is illustrated that only 2% of municipalities present an efficiency score between 0.0 and 0.6. The histogram shown on Figure 4 evidences that the 85 municipalities present a homogeneous behavior when performance is assessed based on eco-efficiency index.

Figure 3: Eco-efficiency scores of the Spanish municipalities evaluated.

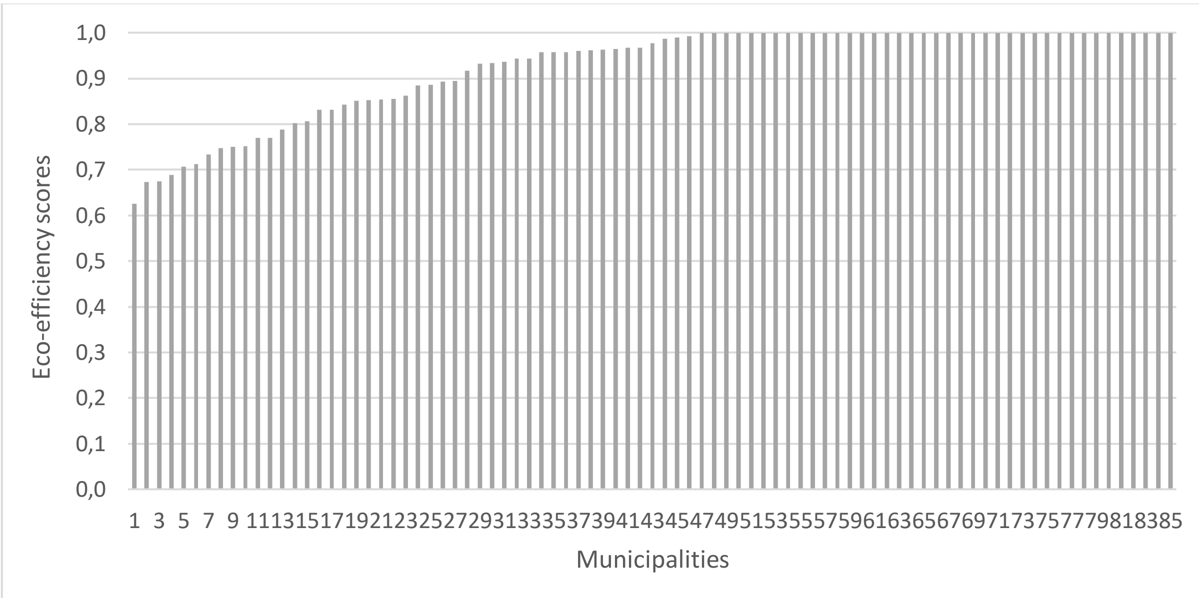
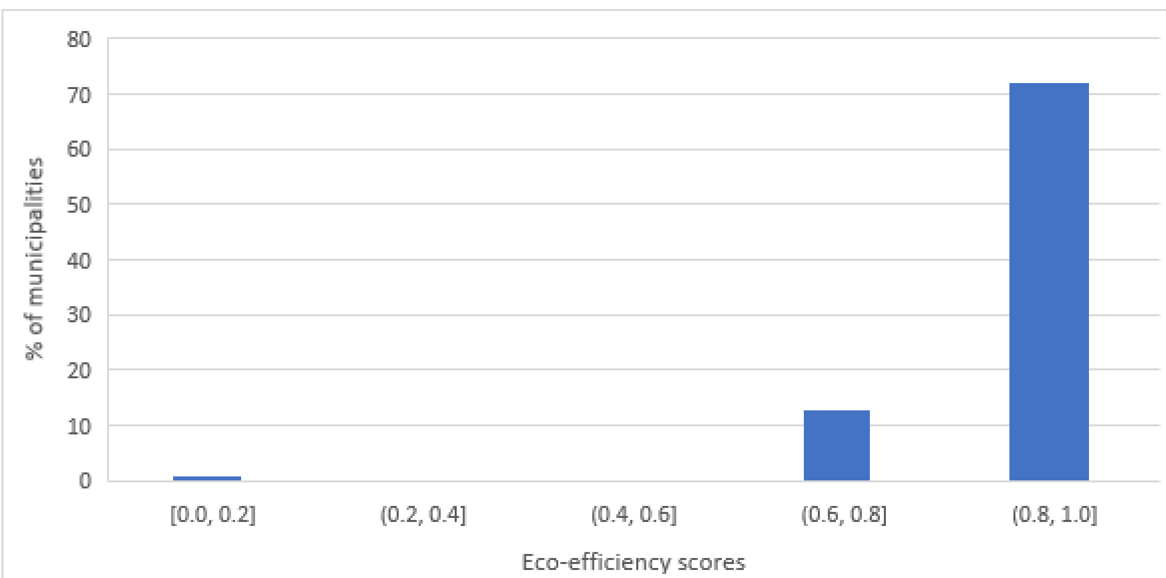


Figure 4: Histogram of eco-efficiency scores of the Spanish municipalities evaluated



To evaluate the impact of separate collection and recycling on the performance of MSW management services, Figure 5 shows the difference between the eco-efficiency and efficiency scores. It shows that 8 out of 85 municipalities (9.4%) of the municipalities present a negative value which means that their efficiency score is larger than the eco-efficiency one. It means that these municipalities have better performance when separate collection and recycling of waste is not integrated in the assessment. It suggests that these municipalities have poor performance in waste separation and collection. Figure 5 shows that 22 out of 85 municipalities (25.8%) obtain values equal to zero, which means that they have the same efficiency score index value when efficiency and eco-efficiency are compared, that is, they are efficient with both models. The remaining municipalities (58 out of 85, 68.2%) present positive values, i.e., eco-efficiency scores are larger than efficiency ones. It involves that a notable cost of providing MSW services is devoted to separate collection and recycling.

Figure 5: Differences in efficiency and eco-efficiency scores Spanish municipalities evaluated

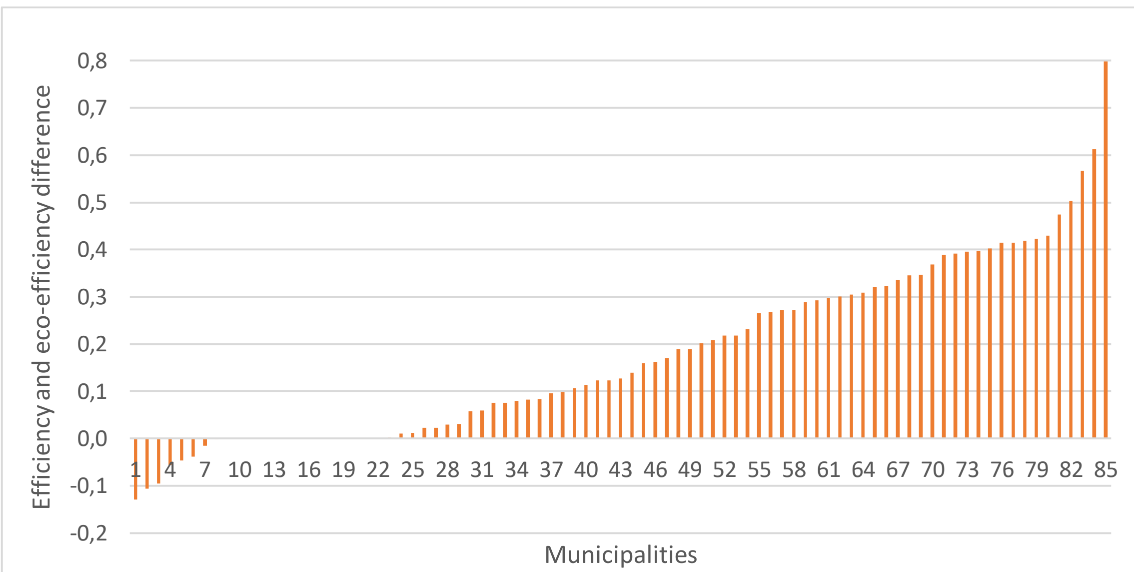
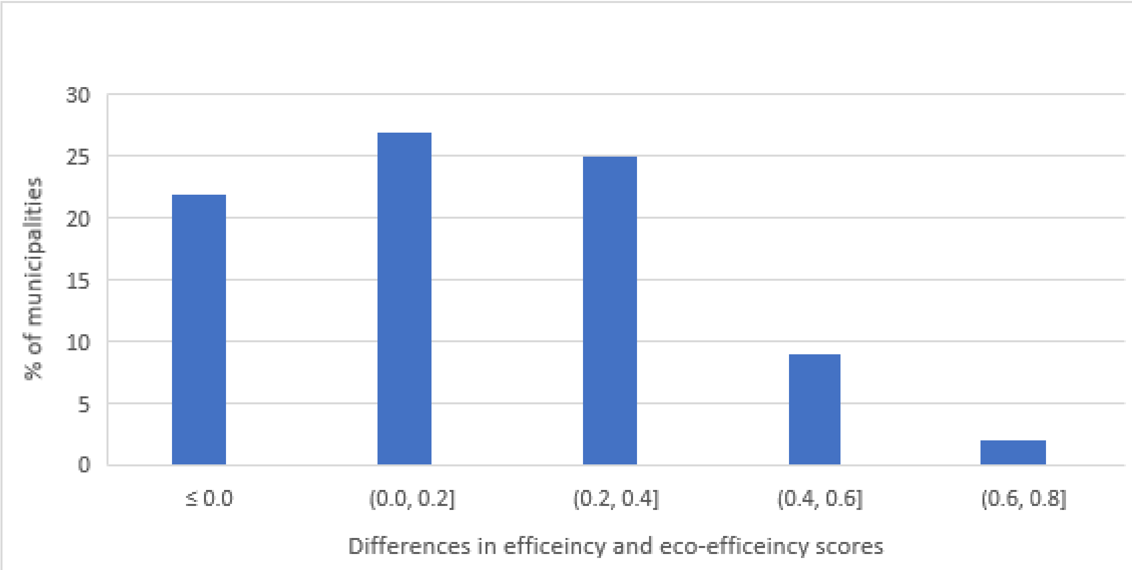


Figure 6: Histogram of efficiency and eco-efficiency scores Spanish municipalities evaluated



The histogram shown on Figure 6 illustrates that there are 27 municipalities that have an efficiency and eco-efficiency difference between the 0.0 and 0.2. This positive value means that municipalities are more efficient when they consider the unwanted outputs, either the separation from their origin or the recycling of their waste, such as it is seen in the histogram of Figure 6.

Finally, the results show that the most notable difference in the efficiency score occurs in the 80th municipality, with 61.3% and 84 municipalities with an improvement potential of 79.8%, in these two units, the collection of waste. It works better, considering the selection of your waste. This result is related to better access to transfer stations, the implementation of the concept of economies of scale by municipalities.

Another point to consider regarding the costs of managing waste, are the associated fees, as described in their research [14], they say that when performing an efficiency analysis, they analyze their costs through different ways of providing waste management services, where there is a constant debate between private, municipal contract and now lately consider economies of scale with inter-municipal cooperation.

5. Conclusions

The importance of urban solid waste management is that it is an essential service, which must be addressed in an interdisciplinary manner. This document deals with the analysis of the impact of separate collection and recycling of waste in the performance of MSW management by municipalities. In doing so, efficiency and eco-efficiency scores were computed for a sample of Spanish municipalities using the DEA method assuming variable returns to scale input orientation. Among the variables selected for this study, it is highlighted that glass, plastic and paper collected and recycled were integrated as desirable outputs and unsorted waste as undesirable output.

Although the studied performance of the Spanish municipal waste management is carried out through private companies, the data obtained represent a large percentage of inefficiency in the separation and non-separation of waste. This 51.8% inefficiency reveals that the municipalities where it is possible to improve their management would be convenient to include more variables in the DEA method since the demographic variables add other recyclable materials that can contribute to improving the efficiency scores.

It should also be taken into account that within the results of the efficiency and eco-efficiency score obtained; there is 52% of the municipalities that are inefficient in both models studied.

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