Municipal solid-waste recycling market and the European 2020 Horizon Strategy: A regional efficiency analysis in Spain.

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Abstract.

This paper focuses on the analysis of the efficiency of Spanish regions in the development of the recycling market in their respective territories through the use of a novel Data Envelopment Analysis method with multiple outputs. The efficiency analysis takes into account the mandatory goals of reducing mixed-collected municipal solid waste and the augmentation of selective collection of recyclable materials, as set by the European Union and the Spanish legal framework. This issue is highly relevant, since neither of these two management goals may be achieved without the recycling market and its associated industry having been previously developed to a sufficient level. Results confirm that Catalonia, Navarre and Madrid function as benchmark regions to be emulated by the remaining inefficient regions. The necessary regional investments and output projections to reach an efficient development of the recycling sector are also estimated. Additionally, it is found that per capita income and population density significantly explain differences in regional efficiencies. Finally, taking efficient regions as benchmarks to learn from, some policy recommendations are offered.

Keywords: municipal solid waste management, waste recycling, waste reduction, recycling market, Spain.

1. Introduction.

Recycling of municipal solid waste (MSW) plays a crucial role in a sustainable society, where waste management strategies should promote an efficient development of MSW recycling markets. The intensifying governmental focus on improvements in the efficiency of MSW management has prompted a major development of public policies in recent decades (Porter, 2002), including those related to the selective collection of MSW and recycling (Guerrini et al., 2017). Traditionally, researchers have described MSW management from a strategic decision-making perspective in an effort to improve performance (Lavee, 2007), thereby producing a wide variety of literature where different methodologies are applied in order to evaluate the economic efficiency of MSW services in a specific country or in cross-country comparisons. Along these lines, the assessment of alternative MSW recycling programs and policies has attracted the attention of the academic community in the US (Feiock and Kalan, 2001), Europe (Haas et al., 2015), as well as in other parts of the world.

In the European context, the EU 2020 strategy provides a guide for a sustainable society in the efficient use of resources. It sets the goals and means to transform the current economy, which is based on the intensive use of resources, into a new growth model based on efficient resource use and where waste is reincorporated into the production process for the production of new products or raw materials (EC, 2010, 2011). In this model of an efficient circular economy, the recycling of waste plays a significant role, by allowing increased availability of resources for the industry, by reducing the environmental impact associated with waste management, and by promoting job creation and investment in the recycling sector. The promotion of recycling and reuse as an economically attractive business option for private agents and the development of functional markets for recycled raw materials have therefore become essential in the current context (EC, 2016).

In Spain, regional and municipal governments are responsible for the development and management of MSW services in their territories under European and national legal directives. Although heterogeneity among Spanish regions is very high, and the economic resources invested into developing functional markets for recycled MSW have increased in recent decades, efforts to increase recycling rates through the selective collection of MSW recyclable materials remain largely insufficient (MAGRAMA, 2015). Thus, the debate on the need for the revision of the Spanish current model of MSW recycling and management has been opened since the goals set by the EU 2020 strategy remain far from being achieved (EC, 2016).

The present work focuses on the analysis of the efficiency of Spanish regions in the development of the recycling market in year 2013, subject to the fulfilment of two mandatory goals (as specified by the EU 2020 strategy and the Spanish legal framework): firstly, the need to reduce the amount of mixed-collected MSW; and secondly the necessity to increase the selective collection of recyclable waste materials. This is of great relevance, as neither of these two goals may be achieved without the recycling market and its associated industry having first been developed to a sufficient level. Therefore, Spanish regions have yet to develop a sufficient operational capacity of their recycling sector in order to attain higher recycling rates (MAGRAMA, 2015).

The main contribution of this paper is twofold. Firstly, it represents one of the few attempts to assess the efficient development of the MSW recycling sector at a regional level through the use of this specific methodology for efficiency assessment. Secondly, it is also one of the first applications of efficiency analysis and benchmarking in the recycling sector in the context of the EU 2020 strategic goals. Therefore, this study proposes two research objectives.

The first is the estimation of efficiency measures across Spanish regions through the application of an alternative radial Data Envelopment Analysis (DEA) methodology with the incorporation of two types of outputs: desirable and undesirable. Data Envelopment Analysis (DEA) is a popular technique developed in the Operations Research and Management Science literature (Farrell, 1957) for the evaluation of the efficiency of a set of similar activity units (e.g., organisations, institutions, regions) which use a multitude of inputs to produce multiple outputs in operational environments, typically characterized by a lack of reliable information on prices and the functional form of the production or cost function. The classic DEA models, including the C2R model by Charnes et al. (1978), the BC2 model by Banker et al. (1984), the FG model by Färe and Grosskopf (1985), the ST model by Seiford and Thrall (1990), and the WY model by Wei and Yan (2010), all solve linear programming problems to obtain a measure of relative efficiency under different assumptions (i.e. returns to scale). A thorough review of the DEA literature and applications can be found in Liu et al. (2013) and Zhu (2016). In the field of the efficiency of MSW services, the majority of studies have used an input-oriented approach, considering outputs as desirable outcomes of the production function and assessing cost efficiency across a group of municipalities or regions. Good examples of the use of this methodology are given in the studies developed by Bosch et al. (2000), Chen et al. (2010), and Rogge and De Jaeger (2012), among others. Several of these studies have focused on the evaluation of the efficiency performance of certain MSW services, such as collection (Bosch et al., 2000) and incineration (Chen et al., 2010). DEA techniques have also been widely used in the assessment of the environmental dimension of alternative MSW treatment technologies (Sarkis and Weinrach, 2001) or in the analysis of the impact of the public-private dichotomy on the cost structure of MSW services (Chen and Chen, 2012). Furthermore, another group of studies, such as those by Chen and Chang (2010), Chen et al. (2012), Chang et al. (2013), and Yeh et al. (2016), have also developed and applied complex DEA methods, constructed upon a multiple-output specification with desirable and undesirable outputs, to the efficiency assessment of MSW services.

In the Spanish context, Gallardo et al. (2010) applied DEA to estimate the efficiency of MSW collection services in various Spanish cities, and Benito-Lopez et al. (2011) used DEA techniques to assess the efficiency of Spanish municipalities at providing street-cleaning and refuse collection services. Although research applications of DEA methods remain extensive in the field of the efficiency evaluation of MSW services and technologies, the methodological approach used in this work has not yet been applied to the waste sector.

The specific DEA method used in this study allows us to ascertain the extent to which the recycling market associated to MSW treatment is sufficiently developed in the Spanish regions and to estimate the necessary output and input projections, in order to reach an efficient development of this sector. Therefore, our efficiency score can be defined as "the capacity to promote the expansion of the regional recycling sector constrained to the fulfilment of two alternative goals, that is, the increase in the selective collection of MSW recyclable materials, and the reduction of mixed-collected MSW, in relative terms".

Thus, the estimated efficiency score would be the result of achieving the following goals simultaneously: 1) an expansion of the regional recycling sector (given by operational revenues of the sector); 2) a reduction of the total amount of mixed-collected MSW; and 3) an increase in the selective collection of MSW recyclable materials (as a percentage of total recyclable MSW). A detailed explanation of these output variables, as well as the method used, is provided in Section 3 of this work.

Secondly, in order to obtain explanations regarding regional differences in the estimated efficiency scores, we contrast whether these differences may be explained by certain socio-economic factors. This will help us to better evaluate future policy strategies in the context of the Spanish regions.

To the best of our knowledge, neither of these two research objectives has yet been treated at a national level or at a regional level. However, we also recognize the limitations of performance evaluation techniques and of benchmarking. The rest of the paper is structured as follows. First the case study is presented. Subsequently, Section 3 briefly describes the DEA methodology and the data used. The results and a short discussion are given in Section 4. Finally, Section 5 offers several policy recommendations, and the conclusions are summarised in Section 6.

2. Case Study.

The Waste Framework Directive 2008/98/EC, as part of the European waste legal framework, has enabled the better uniformity of EU law application and waste management policies (EC 2010, 2011). Furthermore, it has served as an incentive to achieve goals of a more ambitious nature in MSW management (Costa et al., 2010).

Following EU mandatory goals, MSW is to be prepared for reuse or recycling "to a minimum of 50% by weight overall" by 2020, including at least the most common recyclable materials such as paper, metals, plastics, and glass (EC, 2010, 2011). Despite the common EU legislation, the agents responsible for achieving these targets differ between member states, ranging from highly centralized systems (e.g. Austria, Germany) to mainly decentralized systems (e.g. Spain), where regional or local responsibility predominates and various MSW systems are adopted throughout the country.

The Spanish Waste Law 22/2011 transposes the European Directive into Spanish law, by forcing the development of management plans at national and regional level, and enabling local authorities to develop MSW management programs within the scope of their powers. This law gives the government the power to establish the minimum objectives that regions must meet in relation to reduction in waste generation, to recycling, and to other forms of compulsory municipal waste treatment.

In this regard, Spanish Law 22/2011 establishes the need for the Spanish regions to develop a Regional Waste Plan before the end of 2016, and to meet, among others, the following objectives by the horizon of year 2020:

1) Promotion of the recycling industry as the only way to turn used materials into new products that can be marketed, and to advance towards an efficient circular economy.

2) Reduction of the total amount of MSW per capita, with special emphasis on the need to reduce mixed-collected (non-selective disposal) waste. By 2020, it is mandatory to achieve a reduction of at least 10% with respect to the level registered in 2010.

3) Implementation of selective collection systems of different recyclable waste (i.e. paper, plastic, glass, metals, and bio-waste) by 2015 in all municipalities.

4) Increase in the selective collection rate of up to 70% by 2020 of recyclable materials (glass, paper/cardboard, plastic and metal waste).

Although most of the legal framework on MSW management is made at the national level, Spanish regional governments are, as previously mentioned, responsible for designing and developing a regional plan, together with the promotion of certain policies across their municipalities. These plans and policies cover a wide variety of measures, such as the selection from among alternative management models (public, private, or mixed), the choice of alliances between different municipalities to provide communal MSW services to their population, the development of treatment facilities, and the promotion of their recycling sector. Due to the significant public resources allocated to the financing of MSW services, the establishment of efficient management models that would meet the obligations and objectives arising from the National and European legislation remains of particular importance.

To better understand our case study, a map with the regional administrative divisions (commonly known as regions) of the Spanish territory is presented as Figure 1. These regions will represent our assessed decision-making units (DMUs) in the efficiency analysis carried out in this paper. Moreover, Table 1 shows regional heterogeneity in certain variables, such as total population, density (population per square kilometre), GDP per capita, and the amount of MSW generated (kilograms per capita). These variables have been widely discussed in recent literature due to their explanatory relevance of MSW regional performance (García-Sánchez, 2008), as is further discussed in Section 4.

Figure 1. Administrative regional divisions in Spain.

Table 1. Socio-economic indicators in the Spanish regions (2013).

	Population (x1000)	Density (pop./km^2)	GDP (€/cap.)	Total MSW (kg/cap.)
Andalusia	8,381	96	16,666	508.4
Aragon	1,307	28	24,732	407.4
Asturias	1,042	100	20,591	462.0
Balearic Islands	1,106	221	23,446	619.0
Canary Islands	2,100	283	18,873	544.4
Cantabria	582	111	21,550	474.8
Castille-Leon	2,445	26	21,879	381.6
Castille-La Mancha	2,040	26	17,780	418.3
Catalonia	7,516	234	26,666	419.7
Valencia	4,953	215	19,502	403.2
Extremadura	1,086	26	15,026	408.7
Galicia	2,717	93	20,399	365.8
La Rioja	315	63	25,277	410.0
Madrid	6,464	804	28,915	350.9
Murcia	1,464	130	17,901	446.3
Navarre	640	62	28,358	373.9
Basque Country	2,189	303	29,959	470.1

Source: Spanish National Institute of Statistics (INE).

Although the selective collection of recyclable waste materials is widespread throughout the country, collected by the municipalities through appropriate containers and a national code of unified colours (yellow for plastic, blue for paper and cardboard, green for glass, and grey or brown for the remaining types of waste including bio-waste), a significant proportion of the Spanish population is still not sufficiently familiarised and/or have inadequate access to appropriately classified containers, as confirmed by the low rate of selective collection of recyclable MSW in regions such as Andalusia (FEMP, 2015). These collection figures are shown in Table 3. As a result, there is still a great amount of municipal waste that is mixed-collected in street-side containers. After being compacted at a transfer station, this mixed waste is normally taken to a material recovery facility (in the cases that municipalities have access to this type of facility), where the waste is separated out into organic material and recyclable fractions, the latter being sent to recycling plants. Lastly, the various rejected materials obtained in this process are compacted into bales and either sent to be deposited in a land-fill facility or incinerated (with or without energy recovery).

Table 2. Selective collection of MSW in Spain.

Model 1	Model 2	Model 3
Glass	Glass	Glass
Paper /Cardboard	Paper/Cardboard	Paper/Cardboard
Plastic and metal	Plastic and metal	Plastic and metal
Rest	Rest (incl. Bio-waste)	Rest (incl. Bio-waste)
Bio-waste	Garden waste	

Note: Model 1 is mainly implemented in the region of Catalonia.
Source: MAGRAMA (2015).

The three main MSW selective-collection models implemented in Spain at a regional level are shown in Table 2, based on street-side containers. In 2013, there were 21.8 million tons of MSW generated in Spain, of which only 3.9 million tons were sent to recycling plants. Among the main recyclable waste materials, those of paper and cardboard and of glass were the most significant, with 25% and 18% of the total selectively collected amount, respectively (MAGRAMA, 2015).

The heterogeneity across Spanish regions regarding mixed-collected MSW and selective collection of the main recyclable wastes is shown in more detail in Table 3. While Navarre shows the best performance in terms of the minimum rate of mixed-collected MSW (75%) and maximum selective collection rate (36%), the region of Murcia registers the poorest performance due to its high rate of mixed-collected MSW (94%) and its very low rate of MSW selective collection (8%), which is far from meeting the target set by the EU by 2020.

Table 3. MSW collection figures by region (2013).

	Selectively collected recyclable waste (% of total recyclable MSW)	Mixed-collected (% of total MSW)

Andalusia	12.2	94.0
Aragon	17.6	83.1
Asturias	25.1	79.3
Balearic Islands	25.0	88.2
Canary Islands	11.0	93.4
Cantabria	17.6	90.8
Castille-Leon	16.3	89.2
Castille-La Mancha	10.7	92.5
Catalonia	28.9	82.7
Valencia	14.7	91.3
Extremadura	12.1	88.1
Galicia	15.4	90.9
La Rioja	14.0	86.0
Madrid	16.7	86.9
Murcia	8.0	93.6
Navarre	35.4	75.5
Basque Country	30.1	78.5
Average*	17.9	88.3

*Weighted by population
Source: Spanish National Institute of Statistics (INE) and MAGRAMA (2015)

3. Methodology and data.

3.1. Methodology.

DEA methodology represents a non-parametric approach for frontier estimation in the sense that it does not require any assumption about the functional form. Not only does it estimate efficiency scores for each analysed DMU, but it also provides ways to project inefficient DMUs onto the efficient frontier. In DEA, any deviation from the frontier is treated as inefficiency, and there is no provision for random shocks. Furthermore, DEA methods provide a single measure of efficiency even when dealing with multiple inputs and outputs, and thereby obviate the need to assign pre-specified weights to either. These methods measure the efficiency of a DMU relative to the rest of DMUs with the simple restriction that all DMUs lie on or below the efficient frontier. Each DMU not on the frontier (thus, an inefficient DMU) is scaled against a linear or a convex combination of the DMUs on the frontier faced closest to it. For each inefficient unit, DEA identifies the sources and level of inefficiency for each of the inputs and outputs, providing the necessary input and output projections in order to reach the efficiency frontier.

Our particular approach accounts for the peculiar role of an “undesirable” output in order to assess efficiency in its reduction at the same time as “desirable” outputs are maximized. Following recent DEA developments, which have revealed the importance of distinguishing between these two types of outputs as a more complete representation of reality, this study uses an output specification under managerial output disposability as defined by Sueyoshi and Goto (2010, 2011, 2012a, 2012b).

The choice between orientations (input or output) is highly relevant since an inappropriate selection criterion may lead to misleading findings (Avkiran and Rowlands, 2008). Since the aim of our study, for each regional DMU, is to evaluate the relative efficiency at obtaining the selected outputs (both desirable and undesirable), we believe the output specification is appropriate. In fact, outputs in this specific context should be managed by the regional authorities, who remain ultimately responsible for achieving the output goals (as set by the EU 2020 Horizon Strategy).

The efficiency evaluation with this output specification implies that a DMU may increase the directional vector of inputs in order to decrease the directional vector of undesirable outputs. Given the increased input vector, the unit increases the directional vector of desirable outputs as much as possible. This type of efficiency scheme is referred to as “managerial output disposability” and it is commonly associated to the ability of the DMU to adapt to a managerial innovation (e.g. capacity of adaption to new MSW regulations) since it implies a decrease of undesirable outputs through an increase in production capacity (augmented inputs). This scheme produces an autonomous efficiency indicator through the maximisation of the vector of desirable outputs given the disposability of undesirable outputs.

The method employed also explores the associated Damages to Scale (DTS) measurement in order to provide strategic guidance on how to enhance efficiency in the case of particular inefficient DMU and in the whole system of operational units (Sueyoshi and Goto, 2011, 2012c). The concept of DTS differs from, but remains related to, the economic concept of Returns To Scale (RTS). In this regard, while an increasing RTS measurement implies that a unit increase in inputs yields a greater proportion of increase of desirable outputs, which shows that this DMU should increase its size (by an increase of inputs) in order to become more productive, an increasing DTS measurement leads to the opposite result. In this case, a unit increase in inputs yields a greater proportion of increase in undesirable outputs. This result suggests that the DMU should reduce its allocated inputs in order to improve its performance efficiency. The existence of decreasing DTS illustrates a lower proportional increase of undesirable outputs due to an increase in inputs, while desirable outputs are maximized as much as possible. Thanks to this lower proportional increase in undesirable outputs, further efficiency gains may be achieved by an increase in inputs. In the case of constant DTS, an increase in inputs would lead to a proportional increase of undesirable outputs, with no efficiency gains to be achieved.

Our method considers «n» DMUs (in our case study, these represent the 17 Spanish regions) using «m» inputs to yield «s» desirable outputs, but also to yield «h» undesirable outputs.

The «j^{th}» DMU ($j=1,\dots,n$) uses a column vector of inputs (X_j) to yield both a column vector of desirable outputs (G_j) and also a column vector of undesirable outputs (B_j). It is assumed that $Xj=\left(x_{1j}, x_{2j},\dots,x_{mj}\right)^T > 0$, $Gj=\left(g_{1j},g_{2j},\dots,g_{sj}\right)^T > 0$, and that $Bj=\left(b_{1j},\right.$

$b_{2j},\ldots,b_{hj})^T > 0$ for each «*j*» (j=1,…,n), where T means transposed vectors. Structural or intensity variables are expressed with $\lambda = (\lambda_1,\ldots,\lambda_n)^T$, which are unknown and used for connecting the input and output vectors by means of a convex combination. The optimization problem can therefore be defined by the following equation system for each DMU_k ($1 \leq k \leq n$):

$$
\begin{aligned}
\text{Max } & \xi + \varepsilon\left[\sum_{i=1}^{m} R_i^x d_i^x + \sum_{r=1}^{s} R_r^g d_r^g + \sum_{f=1}^{h} R_f^b d_f^b\right] \\
\text{s.t. } & \sum_{j=1}^{n} x_{ij}\lambda_j - d_i^x = x_{ik} (i=1,\ldots,m), \\
& \sum_{j=1}^{n} g_{rj}\lambda_j - d_r^g - \xi g_{rk} = g_{rk} (r=1,\ldots,s), \\
& \sum_{j=1}^{n} b_{fj}\lambda_j + d_f^b + \xi b_{fk} = b_{fk} (f=1,\ldots,h), \\
& \sum_{j=1}^{n} \lambda_j = 1, \lambda_j \geq 0 (j=1,\ldots,n), \xi \text{ unrestricted}, d_i^x \geq 0 \ (i=1,\ldots,m), \\
& d_r^g \geq 0 \ (r=1,\ldots,s) \text{ and } d_f^b \geq 0 \ (f=1,\ldots,h),
\end{aligned} \qquad (1)
$$

where: ξ, which is an unrestricted parameter, represents an unknown inefficiency score indicating a distance between an efficiency frontier and an observed vector of desirable and undesirable outputs; d_i^x, d_r^g and d_f^b are slack variables; and $R_i^x = 1/[(m + s + h)(\overline{x}_i - \underline{x}_i)$, $R_r^g = 1/[(m + s + h)(\overline{g}_r - \underline{g}_r)]$ and $R_r^b = 1/[(m + s + h)(\overline{b}_f - \underline{b}_f)]$, where $\overline{x}_i = \max_j\{x_{ij}\}$, $\underline{x}_i = \min_j\{x_{ij}\}$, $\overline{g}_r = \max_j\{g_{rj}\}$, $\underline{g}_r = \min_j\{g_{rj}\}$, $\overline{b}_f = \max_j\{b_{fj}\}$, and $\underline{b}_f = \min_j\{b_{fj}\}$. In our case, parameter ε takes a value of 0.0001 for the sake of computation convenience, in order to reduce the influence of slack variables.

The objective function implies that two sources of inefficiency can be identified. A DMU_k is efficient if and only if the following two conditions are satisfied: a) $\xi=0$; b) $d_i^x = 0, d_r^g = 0, d_f^b = 0$. In this efficient case, DMU_k belongs to the efficient frontier. It fulfils restrictions in equation system (1), and therefore the objective function is 0. Otherwise, if it is not efficient, the value of the objective function is greater than 0.

The first restriction in system (1) seeks values of λ_j to construct a composite unit, with inputs such that $\sum_{j=1}^{n} x_{ij}\lambda_j = d_i^x + x_{ik} (i=1,\ldots,m)$. The positive slack variables d_i^x indicate that further increases in inputs can be made, which necessarily alter the proportions used, and hence they show the existence of inefficiencies. Similarly, the second restriction, $\sum_{j=1}^{n} g_{rj}\lambda_j = \xi\, g_{rk} + d_r^g + g_{rk}$, tells us that the desirable outputs can be increased or at least maintained by performing a radial expansion ($\xi\, g_{rk}$) and an increase in the slack variable d_r^g.

Analogously, the third restriction, $\sum_{j=1}^{n} b_{fj}\lambda_j = -\xi\, b_{fk} - d_f^b + b_{fk} (f=1,\ldots,h)$, indicates the managerial aspect, since although we have increased the inputs with managerial improvements, it is possible to reduce the undesirable outputs both radially and in their slack variables.

A unified efficiency score (θ) under managerial output disposability is then measured by means of the following equation:

$$\theta = 1 - \left[\xi + \varepsilon\left[\sum_{i=1}^{m} R_i^x\, d_i^x + \sum_{r=1}^{s} R_r^g\, d_r^g + \sum_{f=1}^{h} R_f^b\, d_f^b\right]\right]. \qquad (2)$$

This measure of the unified efficiency score takes values between 0 and 1. If the DMU_k is efficient, then the objective function of equation system (1) is 0, and hence the efficiency score equals 1.

The optimisation problem (1) has the following dual formulation:

$$\begin{aligned} &\text{Min } -\sum_{i=1}^{m} v_i\, x_{ik} - \sum_{r=1}^{s} u_r\, g_{rk} + \sum_{f=1}^{h} w_f\, b_{fk} + \sigma \\ &\text{s.t. } -\sum_{i=1}^{m} v_i\, x_{ij} - \sum_{r=1}^{s} u_r\, g_{rj} + \sum_{f=1}^{h} w_f\, b_{fj} + \sigma \geq 0 \ (j=1,\ldots,n), \\ &\sum_{r=1}^{s} u_r\, g_{rk} + \sum_{f=1}^{h} w_f\, b_{fk} = 1 \qquad (3) \\ &v_i \geq \varepsilon R_i^x \ (i=1,\ldots,m),\ u_r \geq \varepsilon\, R_r^g \ (r=1,\ldots,s), \\ &w_f \geq \varepsilon R_f^b \ (f=1,\ldots,h),\ \sigma\text{:unrestricted,} \end{aligned}$$

where v_i, u_r, and w_f are the dual variables associated to equation system (1).

Optimisation systems (1) and (3) assume that there exists a unique projection on the efficient frontier and a unique reference set of efficient DMUs. In order to eliminate these two assumptions, it is necessary to incorporate strong complementary slackness conditions (SCSCs) into the proposed optimisation problems (Sueyoshi and Goto, 2012a).

Our optimisation problem must therefore be expressed by the following radial model with incorporated SCSCs to measure a unified efficiency score under managerial disposability:

$$
\begin{aligned}
&\text{Max } \eta \\
&\text{s.t. all constraints in systems (1) and (3)} \\
&\xi+\varepsilon\left[\textstyle\sum_{i=1}^{m} R_i^x d_i^x + \sum_{r=1}^{s} R_r^g d_r^g + \sum_{f=1}^{h} R_f^b d_f^b\right] \\
&= -\textstyle\sum_{i=1}^{m} v_i x_{ik} - \sum_{r=1}^{s} u_r g_{rk} + \sum_{f=1}^{h} w_f b_{fk} + \sigma \\
&\lambda_j - \textstyle\sum_{i=1}^{m} v_i x_{ij} - \sum_{r=1}^{s} u_r g_{rj} + \sum_{f=1}^{h} w_f b_{fj} + \sigma \geq \eta \; (j=1,\ldots,n) \\
&d_i^x + v_i - \varepsilon R_i^x \geq \eta \; (i=1,\ldots,m), d_r^g + u_r - \varepsilon R_r^g \geq \eta \; (r=1,\ldots,s), \\
&d_f^b + w_f - \varepsilon R_f^b \geq \eta \; (f=1,\ldots,h) \text{ and } \eta \geq 0.
\end{aligned}
\tag{4}
$$

Equation system (4) incorporates a new variable, η, to obtain an optimal solution that can always satisfy SCSCs. The unified efficiency under managerial disposability is then measured by the following equation, which is equivalent to that obtained by equation (2):

$$\theta = 1 - \left[\xi+\varepsilon\left[\textstyle\sum_{i=1}^{m} R_i^x d_i^x + \sum_{r=1}^{s} R_r^g d_r^g + \sum_{f=1}^{h} R_f^b d_f^b\right]\right] \tag{5}$$

Following Sueyoshi and Goto (2012c), to obtain DTS, it is necessary to estimate the upper bound $\bar{\sigma}$ and lower bound $\underline{\sigma}$ of the following optimisation problems (6) and (7).

$$
\begin{aligned}
&\text{Max } \eta+\sigma \\
&\text{s.t. all constraints in systems (1) and (3)} \\
&\xi + \varepsilon\left[\textstyle\sum_{i=1}^{m} R_i^x d_i^x + \sum_{r=1}^{s} R_r^g d_r^g + \sum_{f=1}^{h} R_f^b d_f^b\right] \\
&= -\textstyle\sum_{i=1}^{m} v_i x_{ik} - \sum_{r=1}^{s} u_r g_{rk} + \sum_{f=1}^{h} w_f b_{fk} + \sigma \\
&\lambda_j - \textstyle\sum_{i=1}^{m} v_i x_{ij} - \sum_{r=1}^{s} u_r g_{rj} + \sum_{f=1}^{h} w_f b_{fj} + \sigma \geq \eta \; (j=1,\ldots,n) \\
&d_i^x + v_i - \varepsilon R_i^x \geq \eta \; (i=1,\ldots,m), d_r^g + u_r - \varepsilon R_r^g \geq \eta \; (r=1,\ldots,s), \\
&d_f^b + w_f - \varepsilon R_f^b \geq \eta \; (f=1,\ldots,h) \text{ and } \eta \geq 0.
\end{aligned}
\tag{6}
$$

$$
\begin{aligned}
&\text{Max } \eta-\sigma \\
&\text{s.t. all constraints in both (1) and (3)} \\
&\xi + \varepsilon\left[\textstyle\sum_{i=1}^{m} R_i^x d_i^x + \sum_{r=1}^{s} R_r^g d_r^g + \sum_{f=1}^{h} R_f^b d_f^b\right] \\
&= -\textstyle\sum_{i=1}^{m} v_i x_{ik} - \sum_{r=1}^{s} u_r g_{rk} + \sum_{f=1}^{h} w_f b_{fk} + \sigma
\end{aligned}
\tag{7}
$$

$$\lambda_j - \sum_{i=1}^{m} v_i x_{ij} - \sum_{r=1}^{s} u_r g_{rj} + \sum_{f=1}^{h} w_f b_{fj} + \sigma \geq \eta \ (j=1,\ldots,n)$$
$$d_i^x + v_i - \varepsilon R_i^x \geq \eta \ (i=1,\ldots,m), d_r^g + u_r - \varepsilon R_r^g \geq \eta \ (r=1,\ldots,s),$$
$$d_f^b + w_f - \varepsilon R_f^b \geq \eta \ (f=1,\ldots,h) \text{ and } \eta \geq 0.$$

Through the use of the upper and lower bounds, the following classification of our DTS measures can be obtained under managerial output disposability for a specific DMU_k:

(a) Increasing DTS ↔ $\overline{\sigma}^* \geq \underline{\sigma}^* > 0$.

(b) Constant DTS ↔ $\overline{\sigma}^* \geq 0 \geq \underline{\sigma}^*$.

(c) Decreasing DTS ↔ $0 > \overline{\sigma}^* \geq \underline{\sigma}^*$.

For the reader interested in the mathematical details of this model, several programmed files have been created with the Wolfram Mathematica software, all of which are at the full disposal of the reader upon request.

3.2. Data.

Consumption of the main production factors, such as fixed capital and labour, have often been included as inputs of the analysed operational DMUs in previous DEA studies. These factors are normally measured in terms of units consumed or, alternatively, in terms of costs by using data from financial statements. The present study uses data on fixed capital and personnel costs from 373 companies (indistinctly belonging to private, public, or mixed management models) that operate exclusively in the operation of recycling facilities where various recyclable materials (mainly glass, paper and cardboard, and plastic and metal) are classified, separated, treated, and prepared to be marketed (these inputs are represented by the vector X_j in the specified optimisation problems). These companies belong to group 38.3 of the EU classification of economic activities NACE Rev. 2 (equivalent to group 5629 of the US NAICS Classification 2012), which includes no information on activities related to the destruction, energy recovery, incineration or land-fill waste disposal. The companies are distributed over all 17 Spanish regions and each operates within a single regional territory. Information regarding fixed capital and labour costs of these 373 companies has been obtained from Bureau Van Dijk's SABI database, checked directly against corporate annual reports of year 2013 and aggregated by region. Additionally, data regarding operational revenue has been collected from this same database in order to be used as an indicator of market development and thus as a desirable output in our study (within the vector G_j in our optimisation problems). Two further output variables have been selected in order to take into account the MSW management goals, as specified in previous sections: the selectively collected recyclable MSW, measured as a proportion over the total amount of recyclable MSW generated, which is considered a desirable output to be maximized as much as possible (as a second desirable G_j output); and the amount of mixed-collected MSW, measured in kilograms per capita, which is considered an undesirable output, and thus must be reduced as much as possible (represented by vector Bj as undesirable output in our DEA model). In this case, the information has been collected from the Spanish Ministry of Agriculture and Environment. Table 4 summarizes the selected input and output variables and their particular specified roles in our DEA model.

Table 4. Selected Inputs and Outputs.

Variable	Description	Classification
Fixed Capital	Indicator of total allocated investment.	Input (X_1)
Labour Cost	Indicator of allocated employment.	Input (X_2)
Operational Revenue	Indicator of regional market development. To be maximized.	Desirable Output (G_1)
Selective collection of recyclable materials (% of total recyclable MSW)	To be maximized, as required by the legal framework.	Desirable Output (G_2)
Mixed-collected MSW (Kg/cap.)	To be minimized, as required by the legal framework.	Undesirable Output (B_1)

In summary, our optimisation model specification contains two main goals in order to assess the regional efficiency in the development of the recycling sector. On one hand, it aims to maximize operational revenue, since this constitutes the main driver for the growth of the recycling business sector and its related market (as required by the European and Spanish legal framework). On the other hand, it aims to maximize the selective collection of recyclable MSW as a desirable goal and, at the same time, to minimize the undesirable output specified as the amount of mixed-collected MSW, which is mainly submitted to elimination and land-fill processes.

Table 5 shows descriptive statistics of our input and output variables. In order to control for problems of sensitivity caused by the existence of outliers and statistical noise, the output/input ratios of each region have been contrasted with the mean value (Miller, 1991). In all cases, with the exception of La Rioja region in two ratios with different outputs, values lie within the range given by the mean value plus/minus 2.5 times the standard deviation. As regards the potential problems that a high number of variables (inputs and outputs) may imply, the condition of the minimum number of observations per variable established by Banker et al. (1996) is met, as we have 17 regions and 5 variables in our model. Thus, potential problems of misspecification are ruled out. The following step, before checking the results, led us to analyse the statistical suitability of the selected variables. Table 6 presents the correlation coefficients between the variables, and shows that input variables have the expected relations with the selected desirable and undesirable output variables. According to Thanassoulis (2000, 2003), the output choice should be based on an analysis of the correlation coefficients, while avoiding the introduction of significantly positively correlated output variables in the same model. As Table 6 shows, our selected output variables present no such problem.

Table 5. Descriptive statistics.

	Fixed Capital (M€)	Labour Cost (M€)	Operational revenue (M€)	Selective collection of recyclable materials (%)	Mixed-collected MSW (kg/cap.)
Average	52.61	2.15	91.81	18.29	384.07
St. Deviation	82.48	1.31	159.41	7.81	71.05
Maximum	299.94	4.30	579.80	35.44	545.70
Minimum	1.08	0.56	1.21	8.00	282.20

Table 6. Correlation matrix of inputs and outputs.

	Fixed Capital	Labour Cost	Operational revenue	Selective collection of recyclable materials	Mixed-collected MSW
Fixed Capital	1	0.532	0.990	0.168	-0.414
Labour Cost		1	0.533	0.660	-0.322
Operational revenue			1	0.185	-0.369
Selective collection of recyclable materials				1	-0.282
Mixed-collected MSW					1

4. Results.

In this section, the outcomes of our efficiency assessment model for the Spanish regions are presented in a step-by-step manner. The first part of this section focuses on the general patterns of the estimated efficiency score within the regions analysed. In particular, our DEA model has identified three efficient regions, which are Catalonia, Madrid and Navarre, as shown in Table 7. These regions register the highest efficiency in the development of their respective recycling markets under our optimization model, and therefore function as benchmark units to be emulated by the remaining regions. In this regard, the method also identifies the relative weight of these three regions as efficient peers of the inefficient regions, as shown by the second column of Table 6. The high weights estimated in the case of Navarre as the most efficient peer, show its relevance as the benchmark regional model over the Madrid and Catalonia cases. On the other hand, there is a heterogeneous range of inefficient regions, where Andalusia and both archipelagos, the Canary Islands and Balearic Islands, register the lowest efficiency scores. The average value (weighted by population) shows a relatively high level of efficiency in the Spanish context (0.792) although the variability in our sample is also high, as measured by the standard deviation (0.144), which indicates the existence of a high interregional heterogeneity. From the efficiency mapping obtained, it can be deduced that southern regions generally tend to register lower efficiency scores than those of the northern regions (as can be identified with the help of Figure 1). This trend is confirmed by the calculation of the efficiency mean values in the two regional groups (0.909 for the northern regions versus 0.665 for the southern regions) as shown in Table 7. Although geographical localization would seem to impose a significant effect, it is demonstrated in a further step of our analysis, that this factor is more closely related to differences in regional per capita income, because regions in northern Spain have generally higher per capita income values than do southern regions.

The second step involves the analysis of DTS estimates (third column in Table 7). As stated in Section 3, a decreasing DTS would show the region's capability to adapt to management innovation based on a decrease of undesirable outputs when desirable outputs are maximized through an augmentation of inputs. In our sample of regions, 12 of the 17 regions show decreasing DTS, meaning that an increase in the allocated inputs in the recycling sector is highly recommended, as efficiency gains can be achieved with the minimization of mixed-collected MSW (kg/cap.) and the maximization of both desirable outputs: the proportion of selectively collected recyclable materials of the total amount of recyclable MSW, and the operational revenue of the recycling business sector.

Only the Basque Country and the Balearic Islands show increasing DTS estimates. In these cases, before allocating more resources, it would be recommended that their regional MSW systems be revised in order to determine the possible causes of inefficiencies, especially in the case of the Balearic archipelago.

The third step consists of the analysis of the output projections regarding the objectives fixed by the European and the Spanish MSW legal frameworks in the Horizon 2020. As previously indicated, regions are obliged to develop and implement regional MSW management plans in order both to augment the selective collection of recyclable MSW and to reduce the total amount of mixed-collected MSW. In this regard, Table 7 shows the projections of these two outputs that are required for each region in order to become efficient or, in other words, to register an efficiency score equal to 1 in the same way as do Madrid, Catalonia and Navarre. Moreover, projected increases of the operational revenue of the recycling sector at a regional level are also shown (fourth column in Table 7). As discussed throughout this study, this issue is highly relevant since MSW management goals may only be achieved through having successfully developed the recycling market and its associated industry to a sufficient level. As shown in Table 7, Spanish regions need to increase the operational revenue of their recycling sector by an average of EUR 19.2 million (that is more than EUR 400 million at a national level, as given by the sum of regional projections), although these projections differ widely between regions.

Table 7. Estimates for efficiency score, efficient peers, DTS, and output projections.

	Efficiency score	Efficient Peers	DTS	Increase in Operational Revenue (M€)	Increase in selective collection (%)	Reduction of mixed-collected MSW (kg/cap.)
Andalusia	0.597	M(0.14), N(0.86)	*Decreasing*	33.8	20.6	192.3

Aragon	0.836	M(0.04), N(0.96)	*Decreasing*	28.2	17.0	55.3
Asturias	0.923	C(0.86), N(0.14)	*Decreasing*	34.8	4.7	28.4
Balearic Islands	0.581	N(1.0)	*Increasing*	25.4	10.5	263.5
Canary Islands	0.555	N(1.0)	*Decreasing*	36.3	24.4	226.3
Cantabria	0.655	N(1.0)	*Decreasing*	33.8	17.8	148.8
Castille-Leon	0.845	M(0.24), N(0.76)	*Decreasing*	39.5	14.7	52.7
Castille-La Mancha	0.729	N(1.0)	*Decreasing*	27.2	24.7	104.9
Catalonia (C)	**1.000**		*Constant*	0.0	0.0	0.0
Valencia	0.775	M(0.14), N(0.86)	*Decreasing*	20.9	18.2	82.7
Extremadura	0.784	N(1.0)	*Decreasing*	18.5	23.4	77.7
Galicia	0.850	M(0.03), N(0.97)	*Decreasing*	14.3	19.5	49.8
La Rioja	0.800	N(1.0)	*Decreasing*	39.8	21.4	70.4
Madrid (M)	**1.000**		*Constant*	0.0	0.0	0.0
Murcia	0.676	M(0.14), N(0.85)	*Decreasing*	38.4	27.4	135.4
Navarre (N)	**1.000**		*Constant*	0.0	0.0	0.0
Basque Country	0.848	C(0.12), N(0.88)	*Increasing*	11.1	4.6	79.3
*Average**	***0.792***			***19.2***	***12.6***	***84.8***
St. Dev.	***0.144***					
Average by geographical location (as specified in Figure 1)*						
North	***0.909***			***10.6***	***5.6***	***34.8***
South	***0.665***			***29.7***	***21.5***	***149.5***

*Weighted by population.

Regarding the desirable projections of the selectively collected recyclable MSW and mixed-collected MSW, the Spanish system as a whole needs to increase its average selective collection of recyclable materials by 12.6 percentage points and to reduce mixed-collected MSW by 84.8 kg per capita, whereby these necessary adjustments are of greater relevance for highly inefficient regions, such as Andalusia and the archipelagos. If we differentiate between northern and southern regions (as illustrated in Figure 1), the average efficiency scores and projections (all weighted by the population of each region) differ widely between these two groups (Table 7).

In a fourth and final step, the analysis focuses on the estimated relationships between our estimated efficiency score and exogenous variables such as population, gross domestic product (GDP) per capita, density of population, and geographical location. According to Bello and Szymanski (1996) and García-Sánchez (2008), the external variables that could typically influence the efficiency of MSW systems are of a socio-economic nature. The most commonly included variables in the literature are population size, population density, and per capita income. While the impact of population size on efficiency scores is generally believed to be positive, debate on the impact of population density remains ongoing (Rogge and De Jaeger, 2013). Regarding income (GDP) per capita, empirical studies such as Shekdar (2009) and De Jaeger et al. (2011) have shown that the theoretical positive relation between income per capita and efficiency is yet to be clarified.

In order to test these relationships in our case study, we have applied an OLS model, which controls for heteroscedasticity with robust standard errors, as well as a Tobit model to determine whether the aforementioned external factors exert a significant influence on the estimated level of efficiency among regions. The two estimation techniques produce similar outcomes in terms of the signs of the relationship and significance levels.

From the results shown in Table 8, it is observed that the served population is revealed to be non-significant and, therefore, does not help to explain the level of efficiency reached by the Spanish regions. A similar result is obtained in regard to a geographical location variable (geodummy). Conversely, the variable of population density shows itself to be statistically significant at a 10% significance level with a negative effect in the estimated regional efficiency score. Finally, the variable of GDP per capita presents a positive relation with regional efficiency, and is statistically significant at the 1% significance level.

Table 8. DEA efficiency analysis on external variables.

	OLS robust		Tobit	
Variable	Relation	*p-value*	Relation	*p-value*
GDP per capita	Positive	0.003***	Positive	0.002***
Geo dummy (North=1; South=0)	Positive	0.309	Positive	0.509
Population	Positive	0.143	Positive	0.113
Pop. Density	Negative	0.060*	Negative	0.082*
R-sq.	*0.4857*		*LR Chi*^{2}	*11.52*

Note: *** Denotes significance at 1%. * Denotes significance at 10%.

These results confirm those of Chang et al. (2013), in the sense that regional governments should determine which recycling policies are more suitable for implementation in their territories, given their community's standard of living. Additionally, the significant positive effect of per capita income on regional efficiency would suggest that regions with better living conditions show better performance at developing their regional recycling markets. Along these lines, Usui and Takeuchi (2014) suggest that the degree of engagement with recycling activities by households depends on income and education levels. Additionally, Yeh et al. (2016) argue that regions with better living conditions have more learning capital, which could improve the effectiveness of public awareness campaigns thereby improving MSW recycling performance. As regions with a high affluence of tourist visitors register indistinctively high (i.e. Catalonia and Madrid) and low efficiency scores (i.e. Andalusia, Canary and Balearic Islands), the "tourism" factor does not seem to explain regional efficiency disparities in our case study. Nevertheless, it must be considered that in the specific case of very touristic regions (as is the case of Catalonia in the peninsula, or the Canary Islands), special socio-political complexities may reduce the feasibility of certain initiatives towards improving MSW management and recycling activities without an effective cooperation of the HORECA business sector (Mateu-Sbert et al., 2013).

Once the inefficient regions are identified, and the discrepancies with respect to efficient regions have been measured through their necessary output projections, then the one question remains: How may these inefficient regions improve the performance of their MSW systems and reach these projected levels? It seems clear that inefficient regions must revise their MSW systems by adopting practices to expand their recycling business sectors and to enhance efficiency at achieving their MSW goals, that is, they should take efficient regional models as benchmarks to learn from. As shown by the estimated results, it seems that southern regions should make stronger efforts in comparison to their northern counterparts, since their presented output projections are more ambitious. In order to offer guidelines, the following section aims to offer several policy recommendations based on the initiatives carried out by the benchmark regions identified.

5. Policy recommendations.

Although no single MSW management system is optimal for all regions due to socio-economic differences (White et al., 1999) and/or political constraints (Goddard, 1995), public authorities should consider policy dissemination and implementation when applying MSW recycling policies (Chang et al., 2013), taking initiatives implemented in efficient regions, such as Catalonia, Madrid and Navarre in the case of Spain as benchmark policies.

The evidence shows that policies to raise the level of the selective-collection of recyclable MSW at source are urgently needed in Spain, as still more than 80% of collected MSW is mixed with all types of household residues (Table 3). Of this mixed-collected MSW, 13% is estimated to be lightweight packaging, 14% corresponds to paper/cardboard waste, 5% to glass, and 47% to organic residues (MAGRAMA, 2015). Although, appropriate policy measures to encourage the development of the recycling sector are still under discussion in the literature (Mueller, 2013), this study aims to offer a number of policy recommendations based on the waste management plans of our benchmark (or fully efficient) regions, which undoubtedly help to explain the positive results and the high level of efficiency achieved by these regions. A summary of the main policy initiatives is shown in Table 9.

The three regions have designed integrated plans for waste management that cover the horizon of year 2020 and incorporate the mandatory goals of the Spanish and the EU legal frameworks (Comunidad de Madrid, 2006, 2017; Generalitat de Catalunya, 2015b; Gobierno Foral de Navarra, 2016). All three regional plans include specific initiatives to encourage public involvement and participation in the development of the management model. Additionally, these regional plans contain strategies to raise public awareness regarding the need for selective MSW disposal and recycling. They establish specific Communication & Education strategies to cover a wide spectrum of social groups, from businesses (including the HORECA and commercial sectors) to private households, and from rural schools to universities. These sector-specific strategies are of major importance since estimates state that between 35% and 45% of MSW can be generated by commercial activities, including those of hotels and restaurants (Bacot et al., 2002).

Moreover, the promotion of the eco-design of packaging by the regional governments of Madrid and Catalonia plays a significant role in the recovery of recyclable materials thanks to close cooperation with the industry sector and the investment of public resources. These initiatives help in the effective implementation of a circular economy model in Europe (Haas et al., 2015). Furthermore, these regions have developed environmental campaigns and programs aimed at promoting the engagement of producers and consumers with a two-fold objective: recycling and minimising MSW generation through green consumption and clean production initiatives. Though green public procurement is a relatively new activity in Spain (Pacheco-Blanco and Bastante-Checa, 2016), the regional plans of Catalonia and Madrid highlight the importance of the consumption of recyclable materials by public regional administrations. In the case of Catalonia, a minimum use of recycled materials in public works has been set by Law.

Efficient and high quality recycling of MSW requires effective selective collection schemes (Ferreira et al., 2017). Evidence shows that a lack of sufficient and adequate facilities can prevent individuals from participating in the waste separation process (Stoeva and Alriksson, 2017). In this same line, Struk (2017) confirms that convenience and distance to the waste separation facility significantly determine individuals' participation in recycling action. Measures contained in the three analysed regional plans aim to assure full and convenient access of the population to selective waste-collection schemes through selective street-side containers for recyclable materials. Moreover, new population developments are specifically considered through continuous investment in new and mobile "clean points" for selective waste collection.

Table 9. Main policy initiatives in benchmark regions.

	Catalonia	Madrid	Navarre
Public participation & consultation	●	●	●
Communication & Education strategies	●	●	●
Eco-design promotion initiatives	●	●	
Consumption of recyclable materials & products - Public sector	●	●	
- Private sector	●	●	●
Continuous investment in "clean points"	●	●	●
Technological learning, innovation and development	●	●	●
Municipalities-Region coordination (clear roles)	●	●	●
Management model based on association of municipalities (common wealth of municipalities)	●	●	●
Alternative funding sources (different from common household taxes)	●		●

Regarding the promotion of technological learning, innovation and development of new recycling and waste management systems, all three efficient regions have developed cooperation initiatives with the industry. Specifically, Madrid includes special cooperative research programs in its regional plan for scientific research and technological innovation. In the case of Catalonia, this cooperation has led to the creation of a technological centre for research, innovation and development in the field of waste management.

With respect to the regional management models, our benchmark regions have two relevant aspects in common. First, regional plans establish clear roles for municipalities and the superior regional government, as well as clear coordination measures in order to gain managerial efficiency. Furthermore, all three regional models are based on the association of municipalities to manage waste services (under a common wealth principle), thereby avoiding individual management models in order to improve efficiency. In this line, Pérez-López et al. (2017) argue that cooperation formulas are associated to higher levels of efficiency in the provision of MSW services, especially in the case of small- and medium-sized municipalities.

Finally, economic resources to fund these management initiatives seem to play a relevant role in the region's capacity to achieve ambitious recycling goals (Feiock and Kalan, 2001). Although the academic sphere seems largely to agree that the financing system associated to MSW management in Spain is inadequate (André and Cerdá, 2006), regional policy-makers often fail to reach any agreement, as evidenced by the regional disparities in this regard. In Spain, municipal waste fees are not usually associated with the amount of waste generated, nor the type of waste, but are generally associated with other criteria, such as the value of the property. Only two regions have begun to implement specific taxes associated to waste generation and treatment (Catalonia and Navarre). The funds raised in this way in Catalonia are directed to a Waste Management Fund, which is used: to prioritize alternative treatment systems; to finance the treatment of selectively collected recyclable waste; and to promote environmental awareness campaigns (Generalitat de Cataluña, 2015a, 2015b). In a similar direction, the regional government of Navarre has proposed a tax reform in order to incorporate an additional charge on waste generation and therefore provide alternative sources of funds from the industrial sector (Gobierno Foral de Navarra, 2016). We believe that these initiatives may contribute towards the generation of the financial resources needed to sufficiently develop the recycling sector in non-efficient regions, since levying taxes on waste and charging recycling fees have shown positive effects in several case studies, such as those analysed by Miranda and Aldy (1998) and, more recently, by Xevgenos et al. (2015).

6. Conclusions.

The DEA method applied has provided an efficiency evaluation of the development of the recycling market reached by each Spanish region conditioned by the achievement of specific MSW goals. The obtained efficiency mapping of the Spanish regions in the development of their regional recycling markets has allowed the identification of three fully efficient regions. These three regions should be considered as benchmark models from which to learn. Results show that there is substantial room for improvement by regional authorities in developing their policies to encourage the selective collection of recyclable waste and to promote the reduction of mixed-collected MSW, and thus capture a greater proportion of recycled materials. Moreover, the estimated projections, along with the DTS estimates, have shown that a majority of regions may reach higher efficiency levels through greater investment in the sector. The DEA technique applied has provided not only a relative performance assessment for each analysed region, but also measurement of the needed output projections, so that policy objectives can be established accordingly.

In this regard, inefficient regions should analyse the replicability of the policy measures implemented in their benchmark regional peers for the improvement of the development of the recycling market within their territory and, at the same time, in order to reach the goals set by the EU 2020 strategy. Additionally, and given the positive impact of per capita income (as a proxy of the regional level of economic development) on the estimated regional efficiency, it seems obvious that policy makers in less developed regions should be especially aware of the efficiency of MSW management investments financed by EU funds, since the reception of future European funding would be conditional on the previous achievement of the EU 2020 goals (EC, 2016).

Since a significant group of regions have recently approved their regional plans or are still undergoing the approval process, future research should analyse the impact of these plans on the efficiency achieved by regions in the development of their respective recycling markets. Finally, we are aware that the static nature of the analysis carried out in this paper represents a major limitation, since a dynamic analysis could enrich the estimated results and the implications for the decision-making process. Since the current Spanish legal framework regarding MSW management was developed in 2011, and the latest available data regarding MSW at a regional level refers to the year 2013, a dynamic analysis in the current legal context remains impossible. Furthermore, it could also be interesting for future research to extend our analysis to include other EU Member States.

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