EFFICIENCY OF SOLID WASTE SERVICES

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Abstract

The present research intended to evaluate the efficiency of the Portuguese solid waste services. It begins by comparing the Portuguese regulatory model with other European countries. Then, it uses the non-parametric benchmarking technique of data envelopment analysis (DEA) to compute the efficiency of 29 solid waste services, including the whole Continental Portuguese population, and was carried out for the year 2005. The DEA model adopted as inputs the operational expenses (OPEX) and the capital expenses (CAPEX), while the outputs were the recycled solid waste volume and the treated solid waste volume. The population density, the Gross Domestic Product (GDP) *per capita* and the average distance to the landfills were the explanatory factors considered. The model orientation was chosen towards inputs minimisation. Several models were calculated, with and without outliers, assuming constant returns to scale (CRS), variable returns to scale (VRS) and superefficiency. The outcomes depicted significant inefficiency. In the case of efficiently operated firms there would be a costs reduction of about 45 million Euros considering the models with outliers and of 22 million Euros in the models without outliers for the year 2005.

Keywords: Data Envelopment Analysis (DEA); Efficiency; Regulation; Solid Waste

1 – INTRODUCTION

The production of solid waste connected with the economic development has become one of the most serious problems modern societies have to face nowadays. Thus, solid waste management transformed itself in one of the main local public services. The municipalities have assumed responsibility for its collection and have established as one of their main priorities to keep the areas under their jurisdiction in adequate aesthetic and hygienic conditions.

The difficulties of the municipalities to cope with the complexity of the solid waste service (Sánchez, 2006), associated with the pressures coming from the European Union (EU), have given origin to reforms in this sector all over Europe in the last years. Some countries, in advance to the EU guidelines, have taken decisions concerning the problems found in the solid waste sector (*e.g.* The Netherlands).

In Portugal this problem was only taken into account after the 1990s, not only due to the continuous growth of the solid waste production but also due to the inadequate treatment facilities (uncontrolled landfills), which reached dramatic proportions. However, in the 1990s there was a significant set of reforms and measures adopted by the Portuguese government that allowed for much progress with regard to environmental issues, becoming an innovative and pioneer country in several fields (*e. g.* in its regulation).

The need for a larger control of the public accounts associated with external pressures both from the EU and the users themselves have raised the awareness of the public institutions to assess and develop the provision of the solid waste service according to the principles of economic efficiency and cost effectiveness.

The number of studies aiming at evaluating the public sector efficiency has become increasingly relevant due not only to the consequent budget restrictions, bearing in mind the public deficit control, but also to the growing importance of this sector in the economy of every country.

As the urban solid waste services usually act as natural monopolies and so, among other reasons, are characterized by reduced incentives towards efficiency and innovation, the evaluation of performance and, in particular, the use of benchmarking can assume an excellent role to challenge this situation. This study intends to apply benchmarking in the Portuguese solid waste sector. Following this introduction section 2 presents the Portuguese regulatory model for the solid waste sector and compares it briefly with three European countries (Spain, the Netherlands and England). Further on, there is a literature review on the efficiency studies in the solid waste sector and in section 4 a performance assessment of the solid waste "wholesale" operators in Portugal is carried out. Section 5 concludes the paper.

2 – SOLID WASTE SECTOR REGULATORY MODEL

2.1 – Institutional framework

The solid waste sector is separated into three segments, namely primary, secondary and tertiary markets. The primary market ("retail" firms) encompasses the process of urban solid waste collection management carried out by the municipalities. The secondary market ("wholesale" firms) comprises the transfer stations, the transportation of solid wastes and their disposal in sanitary landfills and usually regional or national firms are the ones responsible for this process. The tertiary market includes packaging and packaging waste where *Sociedade Ponto Verde* (SPV), member of the international Green Dot system, is responsible for promoting the selective collection, take-back and recycling of packaging waste in Portugal.

The tertiary market in Portugal is based on the SPV job which includes the management and the responsibility for the final destination of the waste produced by the packaging manufacturers or distributors who finance the collection, sorting and recovery of packaging as a payback for the sales packaging service. The role of the municipalities within this system is solely to conduct and sort the packaging waste originating from the selective collection to SPV.

In Continental Portugal there are 29 "wholesale" firms (State and intermunicipal). 15 of them are concessions from which 13 are controlled by EGF (a State company) and 2 by private companies and the remaining 14 are intermunicipal systems. Despite the increasing trend of private sector participation in the "retail" segment, activities such as the non-selective collection of solid waste or urban cleaning are usually carried out by the municipality itself or by means of outsourcing contracts. Currently there are 245 operators, either at intermunicipal systems or direct management by the municipality.

2.2 – Regulatory model

2.2.1 – <u>Introduction</u>

In Portugal there is a regulatory agency, the Institute for the Regulation of Water and Waste (IRAR) for the solid waste rector. This is an atypical circumstance in the European context. IRAR's action is directed to the protection of the users' interests by promoting the quality of service delivered by the utilities and assuring the balance between tariffs based on the principles of essentiality, indispensability, universality, equity, feasibility and cost effectiveness.

Bearing in mind the aim of IRAR`S creation, this institute adopted as its main strategy the public display and periodic comparison (benchmarking) of a set of performance indicators (sunshine regulation). This has become a powerful and effective tool to provide performance incentives by promoting the yardstick competition between the different firms.

2.2.2 – <u>IRAR</u>

2.2.2.1 – Responsibilities

IRAR's scope of action includes the implementation of regulation and guidelines for multimunicipal and municipal systems as well as monitoring the activity of the operators under its jurisdiction, which include the multimunicipal and municipal concessions for water supply, urban wastewater and solid waste management. Besides these chores, it ensures the regulation of the water and solid waste sectors and the balance between the economic sustainability of the systems and the quality of the services in order to protect the public interest. IRAR is also responsible for the observance of technical standards and finally for establishing relationships with similar institutions, either national or international, to improve its own performance. However, there are factors that restrain the role of IRAR, namely the absence of power to apply sanctions and the fact that the local administration bodies in charge of the solid waste direct management until now (September 2007) are not liable to IRAR's action.

2.2.2.2 – Sunshine Regulation

One of the main regulatory tools adopted by IRAR is the so-called sunshine regulation (Marques, 2006a). With the aim of accomplishing this kind of regulation IRAR presents the results of the utilities performance in a report published annually. This document includes an overall evaluation of performance where comparison between utilities are made and an individual qualitative and quantitative assessment of each operator.

IRAR aims at raising awareness of the utilities performance by means of the pressure the consumers and citizens put on them through their defence and representative groups, such as the media, the politicians (Government and political parties) and the NGOs.

The operators with a poor performance become “embarrassed” and will try to correct the deviations. Although this method does not set tariffs and its coercive power is limited, very positive results are obtained with the public display and discussion of the regulated firms' behaviour, introducing competitiveness between them and leading to a progressive rise of performance in the respective market (Marques, 2005).

2.2.2.3 – Quality of Service

One of the main objectives (and also outcomes) of sunshine regulation is related to the quality of service improvement. To accomplish this, IRAR adopts a set of performance indicators which are published in the annual report mentioned above. These indicators measure the operators' efficiency and effectiveness with regard to specific aspects of the activity carried out or the system behaviour.

The solid waste performance indicators translate, alone or in combination between themselves, the *modus operandi* of the systems under analysis (Teixeira and Neves, 2007), despite being known that, *a priori*, the analysis of a single indicator can lead to a biased portrait of reality as they are partial productivity measures which do not incorporate all the associated complexity. Therefore, IRAR developed a set of 20 performance indicators aiming at the protection of the user interests, the operator sustainability and the environmental sustainability.

Finally, IRAR, in addition to its competences and by means of its annual report, issues some comments regarding each indicator for each operator. This evaluation is done according to a system of classification that compares the value obtained with reference values. The latter are optimal values, or close to them, that the regulator deems as likely to be attained by the operators. However, these reference values cannot be analysed *per se* or out of context. Hence, each operator's performance is qualitatively classified as good, average or unsatisfactory to which respectively corresponds a green, yellow or green ball according to the divergence between the result obtained with the indicator and the reference values interval. IRAR publishes the results sorted by performance indicator.

2.2.3 – Public Service Obligations

The services of general interest comprise activities which fulfil basic needs of economic nature to the citizens in general and whose existence is essential to life, health or social participation of the citizens (Marques, 2005). They include, *inter alia*, the sectors of transportation, postal services, energy or any other public service of economic nature “public service obligations”, such as the solid waste sector. These public service obligations should comply with the principles of universality, continuity, quality of service, price accessibility and users protection, among others.

In Portugal, despite the importance of the solid waste sector, there is no such reference in the legislation enacted in this scope.

2.2.4 – Tariffs

The tariff systems implemented by the municipalities in Continental Portugal present a great variability, not only in the way they are charged but also in the corresponding amounts. Currently, the urban solid waste management is under an irrefutable financial lack of sustainability, generated by the insufficient covering of the tariff systems in relation to the solid waste service real costs. The tariffs are proposed by the municipalities and approved in a Municipal Assembly, regardless of the organisational framework (municipal service, municipal service with autonomy or municipal company). The tariffs are established by means of a fixed part and/or a variable part, changing according to the municipality. The income for the service is, usually, discriminated in the water invoice. However, also it can be established according to the frequency of the collection, of the characteristics of the municipality (e.g. area), of the collection system (e.g. door-to-door collection system or by stations) or of the household characteristics. In Portugal, the tariffs implemented by the multimunicipal systems are proposed by IRAR and subject to the approval of the Environment Ministry. The establishment of these tariffs are based on standardised criteria allowing for the total recovery of the costs, namely the depreciation costs and a fair return on equity. This kind of economic regulation is rooted in the American rate of return method.

The tariffs relating to the private “retail” segment are defined by means of a contract at the moment of the public tender for their concession.

2.3 – Comparison with other countries

The current study tried to compare the Portuguese regulatory model of the solid waste sector with other European models (Spain, the Netherlands and England) regarding its organisation and sustainability, by analysing the institutional framework (market structure and private sector participation), the regulatory context and, particularly, the tariff setting process, the public sector obligations and the quality of service provided.

The absence of sector specific regulatory agencies in European countries does seem to point to the idea that *a priori* the solid waste users are more vulnerable to the constraints of monopoly operators (reduced incentives to efficiency and innovation) as there are governments, such as the Dutch, whose role in the scope of the sector's supervision is very intervening (*e.g.*, imposing the principle of "pay-as-you-throw", contributing to the solid waste market self-sustainability).

In England, the aim of the solid waste service provision at the lowest cost as possible has led to a very high number of outsourcing public tenders, creating a vicious cycle. This cycle has culminated in a high competitiveness within the sector and with so low revenues for the operators that they were translated into quality of service deficit or even made it impossible for the operators to provide the service. In face of this situation, the central government implemented the "best value" regime, as opposed to the compulsory public tender as a way to upturn the quality of service and uphold the "value for money".

In Spain, with the opening of the solid waste sector to private operators, conditions were created that enabled the development of several national "champions". If the scale effects can lead to reduced costs, practised by these players, the substantial deregulation that took place in the sector, particularly at the moment of access to the market, can jeopardise the protection of the users' interests of this public service.

3 – LITERATURE REVIEW

3.1 – Studies objectives

The efficiency studies developed in the scope of the solid waste sector are mostly dedicated to its performance evaluation, to the comparison between public and private management and to determine the optimal market structure, particularly concerning the effect of the reforms relative to the sector's unbundling or horizontal integration.

The dichotomy of public *versus* private management has become an eternal issue. Many studies have been carried out, often associated with divergent conclusions depending on the sample and on the technique applied. There has been a growing trend towards the private management of this service over time. In spite of the opposition of some authors to this opinion there is consensus in the incentives provided to the operators by the market and in the existing competition which becomes more important than the ownership (Yarrow and Vickers, 2000 and Bel and Costas, 2006). Other authors defend that the existence of regulation can be an adequate substitute of the market (Marques, 2005). However, even in this situation, the regulation goal is the market building, if not by any other means by yardstick competition. In fact, the competition existent in the sector, unlike the assets or management ownership, becomes the most conditioning factor when the objective is the value for money maximisation within the sector.

3.2 – Techniques adopted

The techniques adopted to determine the efficiency are often classified into parametric and non-parametric. Sometimes they are further divided into frontier and non frontier according to whether they compute the best practices or the average adjustment and stochastic or deterministic if they consider or not the random error (Marques, 2006b).

The solid waste efficiency studies collected from the literature amount to a total number of 55, from which 18 use non-parametric methods and 37 draw on parametric methods. In the group of the non-parametric methods, studies that employ partial measures of productivity are not included. Although the number of studies that use this technique found in the literature is very small, we believe that due to its simplicity and easy understanding this is the most applied in the evaluation of performance by the operators themselves.

As far as the DEA technique and the stochastic frontiers (and deterministic) are concerned, despite the larger number of works under development by academics, there are also some regulators and governmental organisms that apply this type of methodologies (Spain, Australia, etc.). Many studies that appear in literature regard the performance of the municipalities as organizations, including also in this scope the activities provided related to urban solid waste.

3.3 – Studies spatial distribution

The solid waste collection service delivery by the private sector is more and more a current practice. Associated to this situation, there are also a larger number of studies which have been developed with regard to efficiency measurement in countries where the service provision is carried out by private entities. The strong presence of the private sector, namely in Spain, creates an environment favourable to the development of this type of studies.

In Portugal, the research in this scope has been subject to some constraints, not only due to its recent application, Gaiola (2002) and Marques *et al*. (2006) but also due to the lack of information and to the fact that the service is still mostly provided by public entities. The literature has revealed studies in 13 countries, namely the USA, Canada, Switzerland, Spain, UK, Ireland, Denmark, the Netherlands, Sweden, Australia, Portugal, Belgium and Finland.

3.4 – Models specification

Underlying the activity of solid waste services provision, more importance is often observed vis-à-vis certain inputs and outputs to the detriment of others. Consequently some of them are more used than others by the different authors of the studies. For the non-parametric methods adopted, the main variables for the inputs were the number of employees and the total cost of the service (OPEX plus CAPEX). The most adopted outputs were the quantity of collected waste and the number of service users. Regarding the explanatory factors the distance to the landfills and the population density were the ones most often used.

From the 18 studies that employ the DEA technique mentioned in the literature e.g. Vilardell and Riera (1989), Distexhe (1993), Bosch, Pedraja and Suárez-Pandiello (2001), Benito, Bastida and Garcia (2005) and Sanchez (2006), 3 of them try to study the influence of the scale efficiency. From the remaining studies 10 considered only CRS and the other 5 VRS.

Within the span of the models orientation, 12 out of the 18 studies considered oriented models and 6 were non-oriented. It was possible to notice a balance between the studies which had an output maximisation or input minimisation orientation, each one with a number of 6.

4 – PERFORMANCE EVALUATION OF PORTUGUESE SOLID WASTE SERVICES

4.1 – Methodology

The non-parametric frontier technique of DEA is based on mathematical programming to measure the relative efficiency of organizational units which present a homogeneous set of inputs and outputs. Its large use is explained by its several advantages (Marques, 2006b), specifically, the identification of best practices that can be followed by other operators, the computation of the operators optimal size, the estimation of the potential efficiency earnings, the accomplishment of marginal rates of substitution between production factors, the computation of productivity change through time of each operator, the identification of the most efficient operators at each point in time and the determination of the most efficient organizational structure (*e.g.* public *versus* private or bundling *versus* unbundling).

The DEA technique enables the determination of the production frontier and consequently the relative efficiencies of each operator. One of the main advantages is related to the fact that unlike other benchmarking (parametric) techniques it does not need a previous specification to each input/output weight and does not require judgements about the production function. Technical efficiency (TE), obtained by DEA reflects the capability each operator has to spend a minimum number of inputs for a given level of outputs or vice-versa. TE can assume values between 0 and 1, this latter indicating that the operator is efficient and located on the frontier.

In 1978 the so-called CCR model was developed based on CRS and strong disposability of inputs (Charnes *et al*., 1978). Considering the minimisation of inputs we obtain the following formulation where W_k corresponds to the efficiency of each operator that produces the outputs y_i, i=1, …, I, from the inputs x_j, j=1, …, J, with the respective weights a_i and b_j and M is the total number of operators.

$$Max: W_k = \sum_{i=1}^{I} a_i y_{im}$$

$$
\begin{aligned}
& s.a. \\
& \sum_{j=1}^{J} b_j x_{jm} \leq \sum_{i=1}^{I} a_i y_{im} \qquad m = 1, \ldots, k, \ldots, M \\
& \sum_{j=1}^{J} b_j x_{jk} = 1 \\
& a_i, b_j > 0 \qquad i = 1, \ldots, I; j = 1, \ldots, J
\end{aligned} \tag{1}
$$

Later there was the development of a model considering VRS (BCC model) by adding to the previous model the sum of the weights restrictions equal to 1 (Banker *et al*., 1984).

If the TE obtained by CRS (CCR model) are related to those of VRS (BCC model), they can be disaggregated into two components, one due to scale efficiency (SE) and the other due to pure technical efficiency (PTE). This result can be obtained by the application of the DEA models assuming CRS and VRS. If there is a difference between the two TE for the same operator, it means that the operator reveals scale inefficiency and that it can be calculated by means of the results achieved with the different methods. The SE accounts for the degree of savings attained if the operator was operating at an optimal scale.

4.2 – Case-study

4.2.1 – Data collection

The current research aims at evaluating the solid waste services efficiency in Portugal. It included the 29 utilities that act in the secondary market (solid waste treatment), encompassing the whole Continental Portugal population. The year under analysis was 2005 and it was always compared with data available for the year 2004 so as to check some possible divergences.

The data collected was almost always provided by the utilities. However, sometimes the data quality was not very good and it was necessary to do some simplifications. It was also necessary to ask information to IRAR in order to compare information between the available documents every time there was a doubt.

4.2.2 – Model specification

4.2.2.1 – Variables adopted

The model applied for the solid waste services comprises two inputs (operational expenses, OPEX, and capital costs, CAPEX) and two outputs, as previously mentioned. Concerning the inputs the values considered for the CAPEX were the ones present in the account reports regarding depreciation and interest expenses. For the OPEX the model included in the analysis the internal manpower costs, external services, energy, chemicals, other consumables and materials for maintenance and repair and other operating costs. The outputs incorporated all the treated solid waste in the system (including non-hazardous industrial waste) and the recycled waste.

The model also considered three explanatory factors, namely the population density, the GDP *per capita* (by region) and the average distance to treatment facilities (landfills, composting and incineration plants).

4.2.2.2 – Model orientation

The orientation of the model was chosen towards inputs minimisation because, on the one hand, all the utilities have to serve all the urban solid waste users and, on the other, there is a demand minimisation policy for this service. It would make no sense to choose an input maximisation oriented model and there would be no justification for the additional effort of using non-oriented models. Hence, the option was for an input-minimising orientation which attached more importance to the maintenance or improvement of the level of service provided with the minimal use possible of inputs.

4.2.2.3 – Production technology adopted

Several models were computed admitting CRS (CCR model) and VRS (BCC model), as well as other constraints aiming at a better characterization of the production technology. Some superefficiency models, which will be discussed later, along with the adjusting for the environment, were also incorporated in the analysis by means of a second stage where Tobit regression was applied.

4.2.3 – Results

Table 1 presents the summary of the main results obtained for the sample studied with the software of Joe Zhu (Zhu, 2003). Figure 1 shows the TE values and the SE earnings for the Portuguese solid waste services by operator. Figures 2 and 3 show the TE and PTE sorted, by their scores, for the solid waste model.

Table 1 – Results for the Portuguese solid waste services

Values obtained	Model
Average TE	0,590
Average PTE	0,798
Average SE	0,739
Minimum TE	0,205
Minimum PTE	0,291
Minimum SE	0,325
Weighted TE*	0,629
Weighted PTE*	0,899
Weighted SE*	0,709
Weighted TE**	0,629
Weighted PTE**	0,870
Weighted SE**	0,732
Number of efficient operators (TE)	2
Number of efficient operators (PTE)	12

*weighted by treated solid waste; **weighted by population served

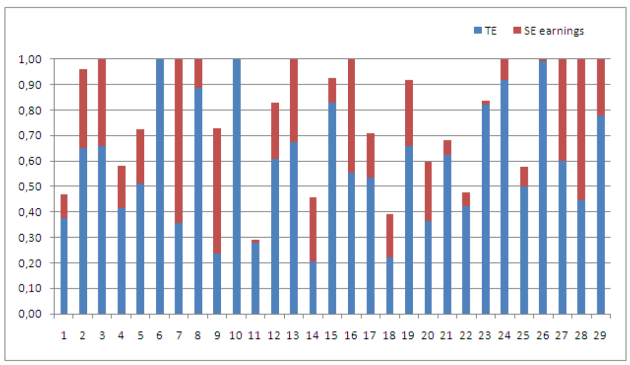

Figure 1 – TE and SE earnings by solid waste service operator

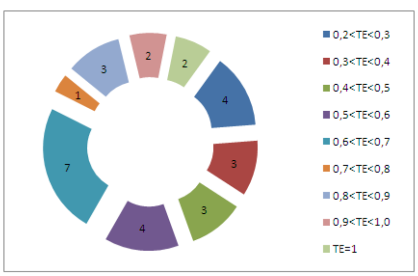

Figure 2 – TE classes for the model adopted

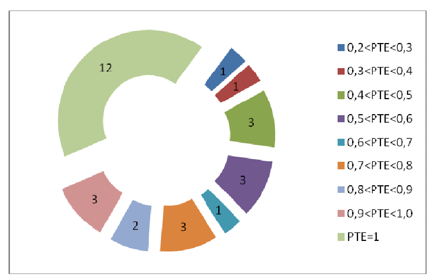

Figure 3 – PTE classes for the model adopted

4.2.4 – Results analysis

The inefficiency levels of the Portuguese solid waste services for the year 2005 were relatively significant, taking into account the average TE whose value was 0,590. In Portugal, the solid waste services show an improvement potential of the average TE of 41,0%, from which 26,1% correspond to SE earnings. This means that, on average, each operator can reduce the inputs consumed by 41,0%, i.e., they can reduce their OPEX and CAPEX and produce the same quantity of outputs(treated and recycled solid waste).

If there was an optimal scale (CRS), the solid waste services would consume less 26,1% of inputs for the same quantity of produced outputs. From the 29 operators, 15 of them present increasing returns to scale (IVRS), 12 decreasing returns to scale (DVRS) and 2 CRS. If the population covered by the service and the quantity of solid waste treated for each operator are considered, the TE value is higher owing to a SE compensation of the operators with a larger population and that treat a larger quantity of waste.

For the Portuguese solid waste services (secondary market) and for the VRS model, the utilities 6 and 27 are more often used as peers. Utility 6 is used 17 times as peer whereas utility 27 is used 10 times. The importance that utility 6 assumes for the others is easily explained by the efficiencies it presents for the model adopted.

4.2.5 – Superefficiency

The model of superefficiency (Andersen and Petersen, 1993) was developed to consider the efficient operators sorting. These measures determinate how much the efficient operators can increase their inputs while remaining technically efficient or, conversely, reduce their outputs keeping themselves efficient. In practical terms, the procedure consists of removing the efficient operators at the moment of their evaluation in the referred algorithms (*e.g.* CCR or BCC), enabling their efficiency to be superior to 1.

From the 11 efficient operators obtained for the VRS model, two of them are unfeasible. The operators with higher superefficiencies are the numbers 6 and 8, presenting values of 2,96 and 5,98, thus requiring special care in the way they are analysed.

4.2.6 – Detecting outliers

In the non-parametric technique of DEA there are always various efficient operators that form the frontier. It is also easily observable that despite the number of operators with efficiency equal to 1 not all of them have the relevance in the sample. Some of the efficient operators are more important than others since they influence the efficiency of a significant set of other utilities. It is essential to give particular attention to these entities, that is, try to check if, on the one hand, they can be outliers or if, on the other, they really are best practices, and so critical for the exercise of benchmarking.

Bearing in mind the indicators peer count, that is, the number of times an operator is peer of other operators (Charnes *et al.*, 1985) and superefficiency, described above, it is demonstrated that operators 6 and 8 are strong candidates to be outliers. After a more detailed analysis to these operators they are atypical cases, namely due to a much reduced CAPEX when compared with the OPEX and to the outputs produced. For this reason, the models presented above were recalculated after removing operators 6 and 8. It is possible to notice a significant rise in the results relative to TE, PTE and SE. The inefficiency level of the Portuguese operators suffers a major reduction after applying this procedure taking into account that the average TE is 0,733. Table 2 presents the results obtained.

Table 2 – Results of the model without outliers

Values obtained	Model
Average TE	0,745
Average PTE	0,886
Average SE	0,841
Minimum TE	0,279
Minimum PTE	0,393
Minimum SE	0,429
Weighted TE*	0,766
Weighted PTE*	0,947
Weighted SE*	0,813
Weighted TE**	0,776
Weighted PTE**	0,935
Weighted SE**	0,833
Number of efficient operators (PTE)	4
Number of efficient operators (PTE)	13

*weighted by treated solid waste; **weighted by population served

In view of this conjuncture, the Portuguese solid waste services have a potential for an average TE improvement of 25,5%, from which 15,9% correspond to SE earnings. This means that, on average, each operator can reduce the inputs in 25,5%, that is, its OPEX and CAPEX, and produce the same amount of outputs (solid waste treated and recycled). If the scale was optimal, that is, in the case of CRS existence, the solid waste services would consume less 15,9% of inputs for the same amount of outputs produced. As previously observed, when considering the population covered and the amount of treated solid waste for each operator, the TE value is superior.

4.2.7 – Adjusting for the environment

The capacity to transform the resources consumed into the products and the desired results does not only depend on the operators TE, but also on the operational environment that characterises them. Likewise, the DEA models results have a limited value if the operational environment where the operators act is not taken into account (Fried et al., 1999).

One of the most adopted procedures for the integration of the operational environment in the analysis consists in the two-stage methodology. In a first stage, this technique solves the DEA algorithm without the explanatory factors. In a second stage there is regression application to the results, where the dependent variable is the efficiency obtained in the first stage and the independent variables are the explanatory factors. The signal obtained for the explanatory factors indicates the influence on efficiency and its importance can be examined through statistical tests. The number of explanatory factors and their type (continuous or categorical) are not relevant to the analysis. The regression formula adopted can be a OLS, although the number of efficient operators advises, or even requires, the Tobit model solving as it adapts better to truncated or censored data (in 1 in DEA models). In the present research, the Tobit model was adopted.

As already mentioned, the explanatory factors considered were the population density, the GDP *per capita* in the area under the jurisdiction of the utilities and the average distance to the treatment facilities. It is expected that the higher the population density and the higher the GDP *per capita* (by region) the higher the efficiencies of the utilities will be. On the other hand, the longer the distance to treatment facility, the lowest the operator's efficiency will be.

The Tobit regression results, obtained with the software Lindep, enable to conclude that the regression coefficients are positive both for the population density and for the GDP *per capita* and negative for the distance to the landfill. Nevertheless, only the GDP *per capita* is statistically significant at more than 95 % and just for the VRS model. Table 3 presents these results.

Table 3 – Explanatory factors statistical significance

Model	Variables	Coefficient	Error	Statistical T	Proba. P
CRS	Population Density	0.00002	0.00013	0,13	0.898
	GDP *per capita*	0.00001	0.00002	9.86	0.389
	Distance to landfill	-0.00369	0.00579	-0.64	0.524
VRS	Population Density	0.00017	0.00013	1.33	0.185
	GDP *per capita*	0.00003	0.00002	1.97	**0.049**
	Distance to landfill	-0.00473	0.00537	-0.88	0.378

Tobit model intends to adjust the TE achieved by DEA (net), by removing the influence of the explanatory factors. Figure 4 compares the results accomplished.

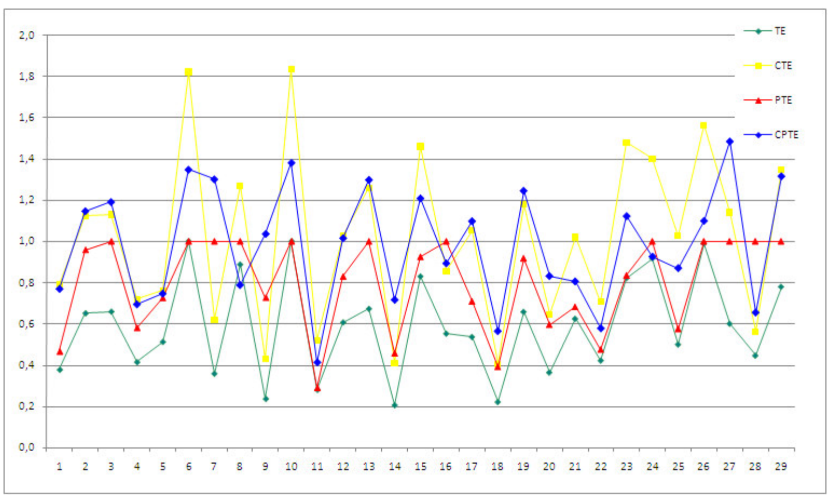

Figure 4 – Comparison of corrected and non-corrected TE and PTE results

5 – CONCLUSIONS

The current research first presented the Portuguese regulatory and organizational model and compared it with those of other countries. The presence of the regulator and the application of benchmarking underline its positive role as it has contributed significantly for the improvement of the quality of the service provided.

Then, the efficiency of Portuguese solid waste services was computed by the non-parametric benchmarking technique of DEA. The models developed, admitting CRS and VRS, allowed to conclude that the Portuguese operators' inefficiency levels for the year 2005 were relatively significant. If the utilities operated in efficient way there would be a cost reduction of about 45 million Euros considering the models with outliers and of 22 million Euros in the models without outliers.

The study carried out has shown that the systems have an optimal size if they comprise about 300 000 inhabitants. The peer count and superefficiency indicators were used to determine outliers and two possible outliers were found. Their removal from the sample changes the results significantly.

Finally, the influence of the operational environment in efficiency was analysed. Regarding the explanatory factors incorporated in the model, namely the population density, the GDP *per capita* and the distance to the treatment facilities (the ones most adopted in literature), it was noticed that only the GDP *per capita* was statistically significant at 95 % and for the VRS model. Moreover, as expected, the operational environment proved to have a significant influence in the operators' efficiency.

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