Water and sewerage operators efficiency in Portugal

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Abstract

Performance evaluation reveals itself as an extremely important tool, being one of the most effective ways for an operator to improve its efficiency through measuring and controlling its main production factors and results. Data Envelopment Analysis (DEA) is a benchmarking technique based on mathematical programming and is one method used to carry out performance measurement, which allows to assess the relative efficiency of a group of operators.

DEA was the chosen methodology to evaluate a set of 191 water supply operators and 190 water treatment operators spread throughout Portugal in 2015. With the implementation of two models with an input and output orientation, the objective was to understand which ones operate more efficiently. The selected DEA model, has as inputs the operational costs, the average main length of pipes and the number of employees of each segment. As outputs, the revenue of water volume and the number of houses served were the chosen criteria.

Amongst 191 water supply operators, 19 were considered efficient with an input oriented model and 8 with an output oriented model. Furthermore, operators located in the central region of Portugal are the most efficient decision units. Regarding ownership, concessionary and delegated operators are more efficient than municipal and municipalized services. Considering the water treatment segment, 16 of 190 operators are efficient with an input oriented model and 9 have a score equal to 1 with an output oriented model. The south region of the country is the most efficient one when compared to the north and central region of Portugal. Concerning their ownership, we conclude that municipal services are more efficient than municipalized operators.

Keywords: DEA, efficiency, economic regulation, water and sewerage services, management models

1 Introduction

Water, an essential commodity to life and to the development of human population, has been considered an unlimited natural resource. However, the economic, demographic and social evolutions occurred in the 20th century concluded that this assumption is far from the reality in which we live. Therefore, it is necessary to implement several measures that will ensure the best management of this commodity in a fair and coherent manner without compromising its sustainability and future generations (Pisani, 1995).

According to the United Nations (2010), access to drinkable water and sewerage systems is an essential human right which every state should respect. In 2015, the United Nations General Assembly, with a new resolution, acknowledged the human right to basic autonomous sewerage system.

Water services and sewerage services, commonly known as services of general economic interest are crucial to welfare of populations, to public health, economic activities and to the environment. For this reason, is necessary to follow a set of principles: universal access, continuity and quality of service and affordability (COM, 2003). Therefore, the water sector contributes significantly to the economic development of a country mainly two ways, by generating economic activity, employment and wealth and allowing to increase the quality of life of the human population (ERSAR, 2016).

The water and sewerage services work in a monopoly regime, where competition is scarce and efficiency incentives are almost inexistent, so it is important to carry out performance evaluation studies allowing, at the same time, to safeguard consumers interests and to control prices and quality of service (ERSAR, 2016). Regulation develops tools which intent to stimulate competitiveness between operators, increasing its performance level in the water sector.

Considering the facts presented, it is critical to perform periodic efficiency evaluations to water and sewerage operators. These evaluations will allow, not only to know the current situation of the sector in Portugal, but also to identify best practices and establish targets to improve their performance. So, this investigation aims to estimate and evaluate the efficiency of a group of Portuguese water and sewerage operators throughout a non-parametric benchmarking methodology, based on linear programming – Data Envelopment Analysis (DEA). The application of this technique will generate efficiency scores according to the inputs and outputs that reflect the production process of water sector operators.

The main objective of this work is to estimate and evaluate technical efficiency of water and sewerage operators in Portugal. This analysis will generate an efficiency ranking to compare operators efficiency scores, and understand the limitations of those with a lower score. Besides, it will identify best practices which should be implemented to improve their performance level. To achieve this purpose, the following analysis will be considered:

- Analysis of water and sewerage operators by region;
- Analysis of water and sewerage operators by management model;
- Analysis of water and sewerage operators in terms of their dimension.

This paper will be structured as follows:

- Section 2: Water sector;
- Section 3: Literature Review;
- Section 4: Methodology;
- Section 5: Case Study;
- Section 6: Results;
- Section 7: Conclusions;
- Section 8: References.

2 Water sector

The water sector in Portugal is based on the French regulation and development, where the responsibility of its services rests with the municipalities. However, the Portuguese framework differs from the French in three main characteristics. First, there's a separation between "bulk" water and direct water. Second, the State is the main operator in the sector. Finally, there's an entirely dedicated regulation entity to the water sector, ERSAR (Marques, 2008).

Since 1993, the sector went through a restructuring process, allowing private capital to enter this market, which contributed significantly to the development of the sector in Portugal. With this opening, municipalities delegated the management of this services to the private sector, increasing the interest of national companies for this industry, creating a need to supervise its activities.

ERSAR was created in 2009, replacing IRAR as a regulatory entity for the water sector. Since the beginning, ERSAR has strengthen its powers, extending its competences, aiming to cover its scope of intervention to all universe of water and sewerage operators.

Water and sewerage are considered services of public interest, even when they are managed by private initiative (Kraemer, 1999). Despite the different objectives of public and private companies, there's a need to find ways to guarantee the welfare of populations and at the same time to present high efficiency levels and good financial results (Marques, 2008).

Table 1 and Table 2 represent, respectively, the geographic distribution of water and sewerage operators according to its business model.

Table 1. Water operators business model

Region	1	2	3	4	Total
North	0	0	73	4	77
Center	1	1	53	14	69
South	0	0	43	2	45
Total	1	1	169	20	191

Note: 1 – Concession; 2 – Delegation; 3 – Municipal Services; 4 – Municipalized Services.

Table 2. Sewerage operators business model

Region	1	2	Total
North	75	3	78
Center	56	12	68
South	42	2	44
Total	173	17	190

Note: 1 – Municipal Services; 2 – Municipalized Services.

3 Literature Review

Since the 1980's, several studies were conducted to evaluate water and sewerage efficiencies applying performance analysis methodology, in particular DEA.

In this review, we will focus on the DEA methodology, which will be detailed and applied further. There are significant variation in terms of the scope of each study: analysis to specific group of water operators of a particular location, like the ones in Japan by Marques *et. al* (2011) or Denmark by Guerrini *et. al* (2015), to a wide scope covering two countries as the analysis done in Portugal and Italy by Da Cruz *et. al* (2012) and England and Wales by Molinos-Senante *et. al* (2014).

There was a great diversity of variables used in each study, according to the defined objectives. Yet, it was essential to perform a literature review to understand the most used variables and their impact on efficiency results. Table 3 and Table 4 show, respectively, the most used inputs and outputs in the literature review performed.

Table 3. Inputs used in literature review

Inputs	Frequency
OPEX (€)	12
Employees (nº, €)	11
Main length (km)	7
CAPEX (€)	4
Cost of material (€)	1
Sewerage treatment capacity (m^3)	1
Material cost (€)	1
Revenue (€)	1
Services (€)	1

Table 4. Outputs used in literature review

Outputs	Frequency
Volume of water sold (€, m^3)	13
Number of clients (nº)	8
Main length (km)	1
Domestic clients (nº)	1
Non-domestic clients (nº)	1
Properties connected (nº)	1
Revenue (€)	1
Volume of sewerage water treated (m^3)	1

4 Methodology

4.1 Introduction

The production process is defined as a process in which inputs are transformed into outputs. The production unit that converts resources into products is denominated as a Decision Making Unit, DMU. Considering the limited resources available in any industry, it is crucial to analyze and evaluate the quality of production, including the efficient use of inputs and the maximization of outputs.

Commonly known as synonyms, the concepts of productivity and efficiency are completely different notions. Productivity is defined as a ratio between the output and the input (Vincent, 1968). Lovell *et. al* (1993), defined efficiency as the maximum achievable outputs considering the available inputs.

According to Farrell (1957), technical efficiency is defined by the relative productivity at a certain time. In an economic context, the production frontier is related with technical efficiency. The allocation efficiency focuses on the optimal combination corresponding to the minimum cost of production.

Performance evaluation is an essential instrument to organizational progress, aiming to define the current state of a firm and to point the future, regarding its objectives and the present results.

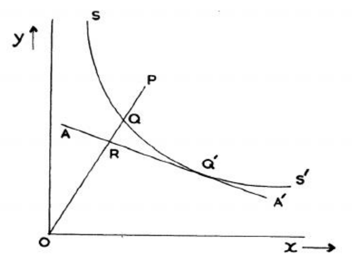

Figure 1. Technical and allocation efficiency with 2 inputs and 1 output (Farrell, 1957)

4.2 Data Envelopment Analysis

Performance measurement is vital to access the efficiency of a group of DMU. In general, we can divide performance measurement methodologies in parametric and non-parametric approaches, which in turn, can be split according to the use of an efficiency frontier (Marques and Silva, 2006).

DEA is one of those techniques, characterized as a non-parametric benchmarking methodology which uses an efficient frontier, based on linear programming (Charnes *et. al*, 1978). It is worth noting that DEA doesn't assess the absolute efficiency of a DMU. It only evaluates the relative efficiency of DMU given that the evaluation only considers a study sample.

DEA has two approaches:

(a) CCR model, developed by Charnes, Cooper and Rhodes (1978), considers constant returns to scale, enables an evaluation of global efficiency;

(b) BCC model, developed later by Banker, Charnes and Cooper (1984), assumes variable returns to scale, and distinguishes between scale and technical efficiency.

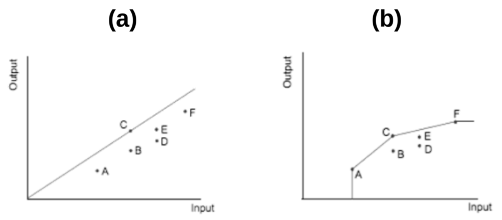

Figure 2. Frontier exemple of CCR (a) and BCC (b) models (Kim and Harris, 2009)

In Figure 2(a), a set of DMUs were classified as efficient using CCR model, in which only DMU identified by point C is considered efficient. In Figure 2(b), representing BCC model, the DMUs identified by points A, C and F are considered efficient.

DEA models have been developed to assess efficiency in several ways: input-oriented and output-oriented models. Input-oriented models are based on the minimization of inputs assuming the same level of outputs, while output-oriented models are based on the maximization of outputs assuming the same level of inputs (Thanassoulis, 2000).

5 Case Study

5.1 Definition of variables and data

The sample used in this investigation contemplates 191 water operators and 190 sewerage operators in Portugal. However, due to lack of information available a higher number of operators were not considered in this study. Even so, the sample used is large enough to support the results obtained, allowing a robust and consistent interpretation of efficiency results. This paper analyses the water and sewerage operators performance for the year 2015. DEA methodology was selected to perform this study.

Regarding DEA models, input-oriented and output-oriented models were chosen, both using CRS and VRS returns to scale.

The selected inputs and outputs for DEA models considered to the objective of this investigation, were the operation process of water and sewerage operators, the literature review and the data availability. This was a critical step because a wrong choice could lead to misleading results.

Hence, the OPEX, the average length of water pipes and the number of employees were the chosen inputs for water operators. The outputs selected were the volume of water sold and the number of houses served by water operators. Regarding the sewerage operators, the selected inputs were the OPEX, the average length of water collectors and the number of employees of these operators. The selected outputs were the volume of water treated and the number of houses served by sewerage operators.

6 Results

6.1 Efficiency results

All efficiency results presented in the following figures were obtained assuming variable returns to scale. As referred in the objectives, several comparisons should be made.

In general terms, water operators under input-oriented model performed better than under output-oriented model, with an average efficiency score of 0,65 and 0,58 respectively. Overall, there are 19 efficient water operators under input-oriented model and only 8 under output-oriented model. The efficiency comparison between input-oriented and output-oriented models by region is shown in Figure 3.

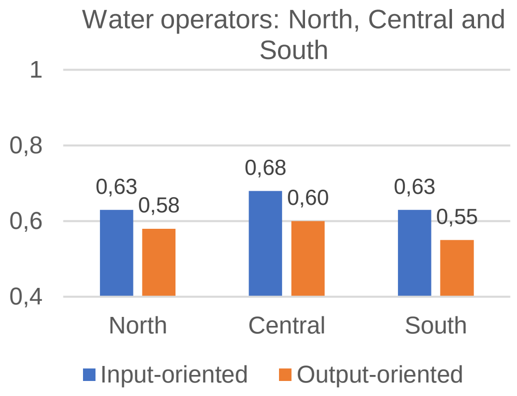

Figure 3. North, Central and South water operators results

Through the observation of Figure 3, we can conclude that the water operators from the central region of Portugal have a higher efficiency score when compared with the operators from the north or south of the country. While the average technical efficiency under input-oriented model in the central region is 0,68, the north and south regions presented the same score of 0,63. Under output-oriented model, the central region still the highest score, while the results indicate that the water operators in the south region have the lowest average technical efficiency score. Furthermore, efficiency scores under input-oriented models were superior than output-oriented models in all regions.

Regarding efficient water operators in input-oriented model, 19% of central operators were considered efficient, against 5% of northern operators and 4% from the south of Portugal. In the output-oriented model, the number of efficient water operators decreased, 7% of central operators were considered efficient, 3% in the north and 2% in the south.

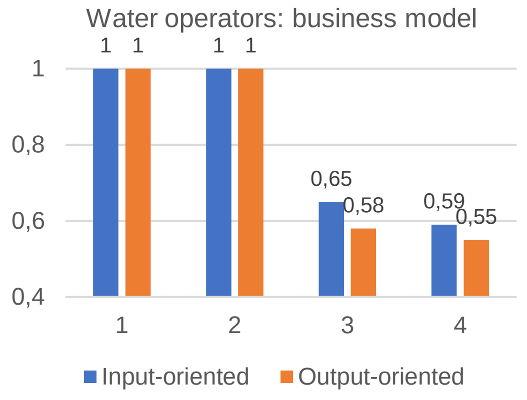

Figure 4. Water operators business model results

Concerning business model, water operators working under a municipal service (3) are more efficient than the ones working under a municipalized service (4), in input-oriented and output-oriented models, as seen in Figure 4. In input-oriented model, the average technical efficiency score of municipal services operators and municipalized services operators is 0,65 and 0,59, respectively. The same tendency occurs in the output-oriented model, with scores of 0,58 and 0,55 for municipal and municipalized services, respectively. It is also important to refer that there was only one operator working under a concession and one working under a delegation business model. For both input-oriented and output-oriented models, the results show that these two water operators are considered efficient, with an efficiency score of 1.

In terms of number of efficient water operators under input-oriented model, 19 were considered efficient working under a municipal service, and 2 achieve a unit score working under a municipalized service. In output-oriented model, 6 municipal services were considered efficient. All municipalized services were considered inefficient under output-oriented model.

In general terms, sewerage operators under input-oriented models have a higher average efficiency score than under output-oriented models, 0,58 and 0,50 respectively. Overall there are 16 efficient sewerage operators under input-oriented model and 9 under output-oriented model. The efficiency comparison between input-oriented and output-oriented models by region is shown in Figure 5.

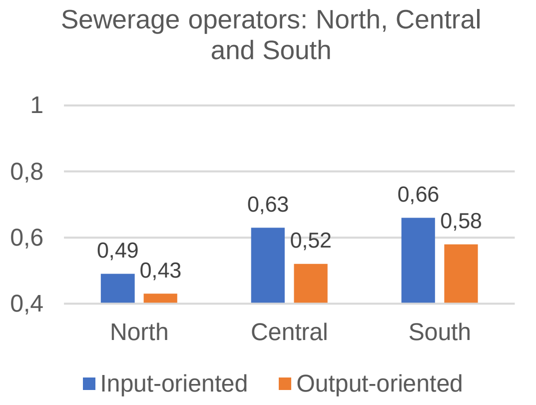

Figure 5. North, central and south sewerage operators results

As shown in Figure 5, sewerage operators from the south region of Portugal presented a higher efficiency score when compared with the north and central regions of the country. The average technical efficiency score under input-oriented model of sewerage operators in the south was 0,66, while the north and the central regions presented efficiencies scores of 0,49 and 0,63 respectively. The difference between these geographic regions were significantly smaller. Still, results under input-oriented models perform better than under output-oriented models.

Considering efficient sewerage operators in input-oriented model, 14% were efficient in the south, against 13% in the central region and 1% in the north of Portugal. In output-oriented model the number of efficient sewerage operators diminished, with only 9% of the south operators to be efficient and 7% of central operators to have a score of 1. It is important to refer that under output-oriented model, none of the north operators were considered efficient.

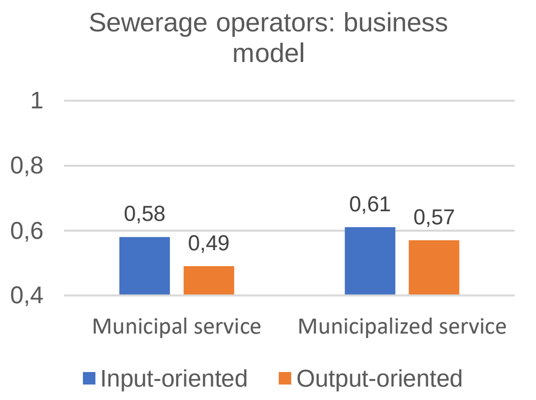

Figure 6. Sewerage operators business model results

Regarding sewerage operators business model, municipalized services revealed less inefficiencies than municipal services both under input-oriented and output-oriented models, as shown in Figure 6. The efficiency score of municipalized services in input-oriented model was 0,61, while municipal services was 0,58. The difference under output-oriented models was higher: municipalized services had an efficiency of 0,57 and municipal services scored 0,49.

6.2 Slacks and targets

Input and output slacks of water and sewerage operators are related with their efficiency level and are representative of an excessive input or a missing output. Input-oriented and output-oriented slacks of water operators are represented in Table 5 and Table 6, respectively.

Table 5. Input and output slacks of water operators in input-oriented model

Variable	Slack
OPEX (€)	54.394,8
Average water pipes length (km)	11,5
Number of employees (nº)	0,2
Volume of water sold (m^3)	765.848,2
Number of houses served (nº)	5,1

The slack of average water pipes length is very low, as well as the slack of number of employees and the number of houses served by water operators. On the other hand, OPEX and volume of water sold slacks are too large to be unnoticed, which means there is great potential of improvement in this two variables.

Table 6. Input and output slacks of water operators in output-oriented model

Variable	Slack
OPEX (€)	20.357
Average water pipes length (km)	11
Number of employees (nº)	0
Volume of water sold (m^3)	1.502.422
Number of houses served (nº)	0

Table 6 shows the slacks under output-oriented model. Similarly to an input-oriented model, slack related with the average water pipes length, the number of employees and the number of houses served are low. In fact, regarding the number of employees and the number of houses served, we can conclude that these two variables are at an excellent level of performance, because their slack is equal to 0.

Considering sewerage operators, input-oriented and output-oriented slacks are listed in the following tables.

Table 7. Input and output slacks of sewerage operators in input-oriented model

Variable	Slack
OPEX (€)	8.453
Average collector length (km)	5
Number of employees (nº)	2
Volume of water treated (m^3)	189.118
Number of houses served (nº)	224

Table 7 represents the slacks of sewerage operators under input-oriented model. As shown, slacks related with the average collector length and the number of employees and the number of houses served are low, which means that these variables are working near an optimal level. On the contrary, slacks related with OPEX and volume of water treated are too large, meaning that there is a great potential of improvement to be explored in these variables.

Table 8. Input and output slacks of sewerage operators in output-oriented model

Variable	Slack
OPEX (€)	157
Average collector length (km)	9
Number of employees (nº)	2
Volume of water treated (m^3)	408.764
Number of houses served (nº)	223

Table 8, shows the slacks of sewerage operators under output-oriented model. Similarly to an input-oriented model, represented in Table 7, the slacks the average collector length and the number of employees and number of houses served are low. On the opposite side, the slack related to the volume of water treated is large. The slack related with the OPEX of sewerage operators stands out in this model, with a very low value, meaning that under an output-oriented model, this variable is near its optimal level.

Table 9. Efficiency targets for SMAS de Vila Franca de Xira in input-oriented model

Variable	Target	Current (2015)
OPEX (€)	2.488.399	10.797.619
Average water pipes length (km)	195	195
Number of employees (nº)	91	124
Volume of water sold (m^3)	18.138.966	8.142.524
Number of houses served (nº)	62.231	62.231

Table 9 represents efficiency targets for water operator SMAS de Vila Franca de Xira under input-oriented model. For this operator to become efficient, it would have to make significant changes in its configuration of inputs and outputs. Mainly, SMAS de Vila Franca de Xira would have to reduce OPEX in 77%, 33 employees to become efficient. This operator would also have to increase the volume of water sold from 8 to 18 million cubic meters to achieve this objective.

Table 10. Efficiency target for SMAS de Vila Franca de Xira in output-oriented model

Variable	Target	Current (2015)
OPEX (€)	10.400.154	10.797.619
Average water pipes length (km)	195	195
Number of employees (nº)	124	124
Volume of water sold (m^3)	8.142.524	8.142.524
Number of houses served (nº)	62.231	62.231

Considering an output-oriented model, SMAS de Vila Franca de Xira would only need to decrease OPEX in 4% to be efficient, as represented in Table 10.

Table 11. Efficiency target for CM de Mourão in input-oriented model

Variable	Target	Current (2015)
OPEX (€)	230.224	299.365
Average water collector length (km)	31	31
Number of employees (nº)	2	2
Volume of water treated (m^3)	148.706	116.913
Number of houses served (nº)	1.892	1.585

Table 11 shows the efficiency targets for sewerage operator CM de Mourão under input-oriented model. To become efficient, a reduction in input OPEX of 23% must occur. Regarding outputs, an increase of 27% and 19% should occur in the volume of water treated and in the number of houses served respectively.

Table 12. Efficiency target for CM de Mourão in output-oriented model

Variable	Target	Current (2015)
OPEX (€)	299.365	299.365
Average water collector length (km)	31	31
Number of employees (nº)	2	2
Volume of water treated (m^3)	328.580	116.913
Number of houses served (nº)	1.585	1.585

Regarding an output-oriented model, no required changes in inputs would be needed, as represented in Table 12. Nevertheless, to CM de Mourão operate efficiently, it would have to increase the volume of water treated to 328 thousand cubic meters.

7 Conclusions

As referred in the beginning of this paper, water is an essential commodity to human life and to the general population. Considered as scarce resource, due to the demographic, economic and social changes occurred in the 20^{th} century, is imperative to implement measures to ensure the correct management of this commodity. Therefore, water and sewerage operators will have to adapt and consider all factors, internal or external, that may have influence in their performance.

Amongst the 191 water operators analyzed, 19 were considered efficient in input-oriented model, while in output-oriented model, only 8 achieved the maximum value of efficiency. Concerning the average efficiency score, with input-oriented model the efficiency level was 0,65 while with output-oriented model this value was 0,58. Thus, we can conclude that water operators are more efficient in input minimization than in output maximization.

Efficiency evaluation by region also allow to determine that water operators in the central region of Portugal are more efficient than its counterparts in the north and south both in input-oriented and output-oriented models. On the other hand, operators located in the south are the most inefficient ones in both orientation models.

Other analysis carried out was related to the management model of each water operator. Conclusions point that municipal services are more efficient than municipalized ones, in both orientations.

Regarding water operators production based on the analysis of their size, it was found that in the BCC model, the higher numbers of houses served, the more efficient results. These results are based on the mathematical structure that characterizes the BCC model, which uses a convexity restriction.

Concerning sewerage operators, amongst 190 operators analyzed, 16 were considered efficient in input-oriented model, with an average efficiency score of 0,58, while in output-oriented model 9 operators were efficient, with an average efficiency score of 0,50. Similarly to water operators, sewerage operators achieve more efficient results in input minimization than in output maximization.

Analysis by region led to the conclusion that the south sewerage operators are the most efficient ones in the country, both in input-oriented and output-oriented models.

Another factor in analysis concerning sewerage operators was their management model: municipal or municipalized service. We could conclude that municipalized services have a superior efficiency score in input-oriented and output-oriented models. However, results indicate that there are more efficient sewerage operators in municipal services than in municipalized services in both orientations.

Finally, an analysis of sewerage operators production based on their size led to a similar conclusion to the water operators analysis. It is expected that for the higher number of houses served that BCC would produce more efficient results.

Given that it was forecasted that the Portuguese population would decrease in the following decades, it would be interesting to analyze if water and sewerage operators that have the best scores today will maintain its efficiency levels in the future. Furthermore, it would be also noteworthy to understand what water and sewerage operators with the worst efficiency levels will do to reduce their difference in comparison to the best ones.

8 References

Banker, R., Charnes, A., & Cooper, W. (1984). Some Models for Estimating Technical and Scale Inefficiencies in Data Envelopment Analysis. *Management Science*, *30*(9), 1078–1092.

Charnes, A., Cooper, W., & Rhodes, E. (1978). Measuring the efficiency of decision-making units. *European Journal of Operational Research*, *2*(6), 429–444.

COM. (2003). Livro Verde: Sobre Serviços De Interesse Geral. *COM(2003) 270 final, Comissão das Comunidades Europeias, Bruxelas, Bélgica*.

Da Cruz, N., Marques, R., Romano, G., & Guerrini, A. (2012). Measuring the efficiency of water utilities: A cross-national comparison between Portugal and Italy. *Water Policy*, *14*(5), 841–853.

ERSAR. (2016). *Relatório Anual dos serviços de águas e resíduos em Portugal - 2016* (Vol. 1). Entidade Reguladora dos Serviços de Águas e Resíduos.

Farrell, M. (1957). The Measurement of Productive Efficiency. *Journal of The Royal Society*, *120*(3), 342–358.

Guerrini, A., Romano, G., Leardini, C., & Martini, M. (2015). Measuring the efficiency of wastewater services through data envelopment analysis. *Water Science and Technology*, *71*(12), 1845–1851.

Kim, M., & Harris, T. R. (2009). Efficiency analysis of the US biotechnology industry: clustering enhances productivity. *The Journal of Agrobiotechnology Management & Economics*, *12*, 422–436.

Kraemer, R. (1999). Public and Private Management of Water Services. *Paper presented at «Semana Internacional de Estudos sobre Gestão de Recursos Hídricos», Foz do Iguaçu, Brasil*.

Lovell, C., Fried, H., & Schmidt, S. (1993). *The*

Measurement of Productive Efficiency: Techniques and Applications. Oxford University Press.
Marques, R. (2008). Comparing private and public performance of Portuguese water services. *Water Policy*, *10*(1), 25–42.
Marques, R., Berg, S., & Yane, S. (2011). *Performance Benchmarking Analysis of Japanese Water Utilities*. *University of Florida, Department of Economics, Public Utility Research Center (PURC) Working Paper*.
Marques, R., & Silva, D. (2006). Inferência estatística dos estimadores de eficiência obtidos com a técnica fronteira não paramétrica de DEA: uma metodologia de Bootstrap. *Investigação Operacional*, *26*(1), 89–110.
Molinos-Senante, M., Maziotis, A., & Sala-Garrido, R. (2014). The Luenberger productivity indicator in the water industry: An empirical analysis for England and Wales. *Utilities Policy*, *30*, 18–28.
Nações Unidas, O. (2010). *General Assembly resolution, 64/292 The human right to water and sanitation*.
Pisani, E. (1995). The Management of Water as an Essential and Rare Commodity. *Water International*, *20*(1), 29–31.
Thanassoulis, E. (2000). DEA and its use in the regulation of water companies. *European Journal of Operational Research*, *127*(1), 13.
Vincent, A. (1968). La mesure de productivité. *Revue Économique*, *20*(3), 546–548.