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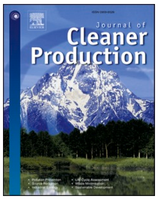

Drivers of water utilities' operational performance – An analysis from the Portuguese case

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ABSTRACT

The identification of the main drivers of performance is key to improve the sustainability of water utilities. The present study aims to identify the relevant drivers associated to the main sustainability-related operational indicators for water utilities, considering both drinking water supply and wastewater treatment. For this purpose, a range of data analysis methods are employed: i) cross correlations analysis to determine the interrelationships between the studied variables; ii) clustering analysis to highlight hierarchical aggregation; and iii) principal components analysis to capture and condense information in a smaller number of composite variables, representative of the service providers diversity. The results highlight the importance of the service provider size on both input and output operational indicators (suggesting the presence of economies of scale), the influence of the allocated personnel and water losses over expenditures and the essential role that the largest service providers attribute to certification policies (environmental and occupational health and safety). The largest and the certified service providers are mostly related to a concession-type governance model and predominantly of urban typology. The policy recommendations that can be driven from these results are the promotion of the aggregation of smaller service providers, the careful control of water losses and personnel allocation, as well as certification practices.

1. Introduction

Sustainability can be defined as the principle of addressing current needs without jeopardizing the ability of future generations to address their own. Taking into consideration the current UN sustainable development goals (UN – United Nations, 2022), the sustainability issue must be deemed of the higher importance for managers, regulators and the general public. In accordance, one should recognize the importance of universal access to clean water and sanitation, goal six of the UN sustainable development goals (without disregarding other goals). Environmental protection, as well as technical, economic and social development, and even governance models, emerge as the fundamental pillars of sustainability. Wastewater (WW) treatment and drinking water (DW) supply systems must also meet these requirements to be considered sustainable (UN – United Nations, 2005; Balkema et al., 2002; Davidson et al., 2007; van Leeuwen et al., 2012; Marques et al., 2015, Molinos-Senante et al., 2016; Dong et al., 2018; Walker et al., 2021; Amaral et al., 2022). In this regard, the present study aims to identify the relevant drivers related to the main sustainability-related operational indicators for water utilities.

The sustainability vectors are interconnected, as more efficient service providers (SP), in financial or technical terms, are able to practice lower tariffs, with the corresponding social implications, and present a greater potential to move towards environmentally sustainable practices. Consumers pay the DW and WW treatment costs through tariffs (SP revenues), thus the SP expenditures are of critical importance addressing costs recovery. In particular, personnel and energy allocation are among the largest operating expenditures (Marques and Monteiro, 2001; Balkema et al., 2002; Davidson et al., 2007; Carvalho and Marques, 2011; Molinos-Senante et al., 2014; Castellet and Molinos-Senante, 2016; Pointon and Matthews, 2016; Dong et al., 2017, 2018; Moreno et al., 2017; Walker et al., 2021; Amaral et al., 2022). Due to the potential to lower external energy demands, the energy produced within a SP is also an important aspect to consider (Walker et al., 2021; Amaral et al., 2022). Furthermore, as global water demands increase, and fresh water supplies decrease, sensible use of clean water is essential

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(Balkema et al., 2002; Davidson et al., 2007). In this context, the ability to reuse treated WW (Gonzalez-Serrano et al., 2005; Hernández-Sancho and Sala-Garrido, 2009; Rodriguez-Garcia et al., 2011: and Amaral et al., 2022) and to reduce DW losses (Ferro and Mercadier, 2016; Molinos-Senante et al., 2016; and Sala-Garrido et al., 2019) is crucial. Sludge production is another issue that must be addressed in WW treatment systems (Balkema et al., 2002; Molinos-Senante et al., 2014; Castellet and Molinos-Senante, 2016; Dong et al., 2018; Henriques et al., 2020; Amaral et al., 2022), imposing costs for the SP due to sludge treatment and/or deposition by third-party entities. Taking all the above issues into account, the current study considers as operational indicators for the SP four inputs (allocated personnel, energy consumption, expenditures and intake DW or WW), four desirable outputs (revenue DW or WW, treated WW, reused WW and produced energy), and two undesirable outputs (produced sludge and water losses).

Literature also shows that, beyond the use of benchmarking techniques, it is essential to identify the main drivers of the operational indicators (OI) normally employed to study the SP performance. Indeed, this is one of the main goals of the present study, using the Portuguese case as an illustration. Previously studied drivers include.

- Size of the SP, with several authors (Byrnes et al., 2009; Romano and Guerrini, 2011; Martins et al., 2012; Carvalho and Marques, 2014, 2015, 2016; Pinto et al., 2017; Molinos-Senante and Guzman, 2018; Caldas et al., 2019; Henriques et al., 2020; Walker et al., 2021; Pereira and Marques, 2022) finding economies of scale up to a certain SP dimension;
- Ownership structure (Romano and Guerrini, 2011; Carvalho and Marques, 2015, 2016; Pinto et al., 2017; Sala-Garrido et al., 2021; Walker et al., 2021) addressing vertical integration and economies of scope between DW and WW, although Carvalho and Marques (2014) found also diseconomies of scope;
- Governance model (Byrnes et al., 2009; Pinto et al., 2017; Molinos-Senante and Guzman, 2018; Caldas et al., 2019; Marques and Simões, 2020; Henriques et al., 2020; Molinos-Senante and Maziotis, 2022) mainly favoring private and/or concession management, although some studies (Cruz et al., 2012; Sala-Garrido et al., 2019; Mocholi-Arce et al., 2022; Pereira and Marques, 2022) do not back this conclusion;
- Geographical location (Romano and Guerrini, 2011; Marques et al., 2014; Pereira and Marques, 2022);
- Customer density and treatment plant (TP) typology (Marques et al., 2014; Carvalho and Marques, 2015, 2016; Henriques et al., 2020; Sala-Garrido et al., 2021; Mergoni et al., 2022) favoring economies of output density, although Molinos-Senante and Maziotis (2021) found otherwise, and favoring urban typology;
- Grid size and connections (Güngör-Demirci et al., 2017) highlighting the need to avoid oversizing;
- Infrastructure maintenance (Ferro and Mercadier, 2016; Palomero-González et al., 2021) towards the need for adequate practices;
- DW sources (Pinto et al., 2017; Molinos-Senante and Maziotis, 2021; Maziotis et al., 2022) favoring the use of surface waters (although these findings were not backed by Pereira and Marques, 2022);
- Service quality (Pinto et al., 2017; Palomero-González et al., 2021) towards the benefit of high quality practices;
- TP age (Molinos-Senante and Guzman, 2018; Molinos-Senante and Maziotis, 2022) presenting mixed results towards energy consumption;
- Treatment complexity (Sala-Garrido et al., 2021; Molinos-Senante and Maziotis, 2021, 2022) towards the use of simpler technologies for eco-efficiency and energy gains.

The most common statistical tools employed in the literature to identify the main drivers for DW and WW SP operational description and performance include the following.

- Non-parametric Mann-Whitney and Kruskal–Wallis tests (Romano and Guerrini (2011) on water utilities efficiency; Dong et al. (2017) on WWTP ecoefficiency index; Moreno et al. (2017) on WWTP energy and environmental performances; Molinos-Senante et al. (2014) on WWTP efficiency, (Molinos-Senante et al., 2015; Molinos-Senante and Guzmán, 2018b) on CO_2 shadow prices (Molinos-Senante and Guzman, 2018) on DWTP energy efficiency; Amaral et al. (2022) on WW SP efficiency),
- Regression methods (non-parametric smoothed regression by Carvalho and Marques (2011) on water utilities performance; multivariate regression analysis by Alves (2016) on WWTP energy use and performance and Amaral et al. (2022) on WW SP efficiency); double-bootstrap truncated regression by Güngör-Demirci et al. (2017) on water utilities performance; convex nonparametric least squares regression by Molinos-Senante and Maziotis (2022) on the energy efficiency of DWTP).

Other employed methods are based on the use of.

- Clustering techniques (*k*–nearest neighbor clustering and principal components (PC) analysis by Macharia et al. (2021) on supply and demand drivers municipal water supply energy input; random forests by Bhattacharya et al. (2021) on arsenic removal technologies of DWTP);
- Correlation or cross-correlation analysis (Spearman's correlation analysis by Molinos-Senante and Guzmán (2018b) on CO_2 shadow prices; cross-correlation by Amaral et al. (2022) on WW SP efficiency);
- Statistical tests (F statistics by Hernández-Sancho and Sala-Garrido (2009) on WWTP efficiency; one-way analysis of variance by Palomero-González et al. (2021) on the evaluation of a water distribution network).

Despite all these studies, in-depth and up-to-date works on potential drivers for the water sector performance with a large set of variables are not abundant, with the above studies focusing, mainly, on a few drivers each. Furthermore, the methodologies employed to analyze the potential drivers have been, for the most part, limited to a single approach, thus restricting the information that can be extracted and being more subject to potential biases driven from the method used. Taking the above in consideration, this study assessed a comprehensive set of potential drivers, regarding the SP dimension, techno-economic, environmental, governance, typology and quality aspects, as shown in Table 2. A range of methods of data analysis tools (which are described in Section 2) was employed to analyze data for the Portuguese case. This allowed identifying the relevant drivers related to the main sustainability-related OI of DW supply and WW treatment SP.

The contribution and novelty of the current study is emphasized by three aspects. First, it relies on the use of a comprehensive set of OI taking into consideration multiple fundamental technical, economic and environmental aspects, comprising, among others, energy consumption and production, reused and revenue DW or WW and sludge production indicators, rarely focused on published literature relating to SP. Second, it encompasses a comprehensive set of potential drivers (dimension, techno-economic, environmental, governance, typology and quality), seldomly addressed in such depth. And third, it provides for a holistic approach (considering a range of methods such as cross-correlation, hierarchical clustering analysis and a PC analysis) regarding the enlightenment of the main OI drivers, thus complementing and enriching the conclusions that can be obtained from the use of a single approach. Furthermore, in addition to being, to the authors best knowledge, the first research focusing on SP with such comprehensive scope and depth, in Portugal or elsewhere, the presented methodology has the potential to be employed with data from other countries to reveal role model SP and corresponding operational drivers and to provide policy recommendations.

The Introduction section described the addressed contextual framework and its state-of-the-art, presenting the focus and main objectives of this study. Next, the Materials and Methods section explains the data collection process, selected operational indicators and potential drivers, as well as the main statistical approaches employed in this study. The main results are presented in the third section, divided into absolute and normalized data findings. A thorough discussion is also carried out in this section. Finally, the Conclusions section sum up the main findings and conclusions withdrawn from this work.

2. Materials and methods

2.1. Data collection

The data used in this work was collected from the Annual Report of Water and Waste Services in Portugal (RASARP) from 2015 to 2019 (ERSAR – Regulatory Authority for Water and Waste Services, 2016; 2017, 2018, 2019, 2020). As OI, the input variables were energy consumption, allocated personnel, total expenditures and intake DW or WW. The desirable output variables were energy production, revenue water, treated WW and reused WW, whereas water losses and sludge production were considered as undesirable outputs (Table 1).

WW and DW SP need to employ a given set of resources (mainly energy, material, financial and human) in order to fulfil their goal. Such resources were considered as input variables in the present study, aiming at identifying the drivers on which the SP should act upon in order to minimize their consumption. The fundamental input of DW SP is the amount of intake water that the treatment plants need to process in order to attend to the consumer DW needs. Likewise, regarding WW SP, the fundamental input reports to the amount of intake WW that needs to be processed before being able to be safely discharged into the receiving water body. Furthermore, as these two variables profoundly affect all other OI variables, they were also employed for normalization purposes in a second analysis. As previously addressed, the SP expenditures are of critical importance addressing costs recovery and, ultimately, water tariffs (SP revenues). Two of the main operational expenses arise from personnel allocation and energy consumption, thus these parameters were also included in the selected input variables. Moreover, energy consumption represents, by itself, an environmental concern leading to the emission of greenhouse gases when obtained from non-renewable sources.

On the other hand, WW and DW treatment operations yield a number of different direct, and indirect, products and byproducts. Such products were considered as output variables in the present study. Revenue water and treated WW are, obviously, the main products (outputs) of WW and DW treatment operations, respectively, and considered of interest (desirable). Other desirable (by)products, from both an economical and environmental standpoint, are the produced energy and reused WW. As previously referred, the produced energy within a SP has the potential to lower external energy demands (and, thus, their energy consumption). The reuse of treated WW allows decreasing the need to use fresh water sources. On the other hand, DW losses represent a burden, both financial and environmental, to DW SP, thus being considered as an undesirable output in the present study. Indeed, apart from potentially reducing the SP revenue water volume, water losses increase fresh water demands. Finally, sludge production was also considered as an undesirable output given that, despite its energy generation potential, it currently represents a financial burden to the Portuguese SP that need to pay third-party entities for its treatment and/or deposition.

Given that the objective of a service provider should be the maximization of desirable products and minimization of undesirable outputs, the analysis of variables influencing the magnitude of these OI was performed according to the manner that they influence sustainability, i.e., in the perspective of increasing desirable products and decreasing undesirable products.

Expenditures were converted to constant 2018 prices. Excluded from the study were the SP that: i) did not operate drinking water treatment plants (DWTP) in the DW sector; ii) did not operate wastewater treatment plants (WWTP) in the WW sector, or iii) with missing data (except for economic data that could be estimated from annual financial reports). A final identification and removal of potential outliers resulted in a total ranging between 38 and 46 SP analyzed in the DW sector and 126 to 130 SP in the WW sector, between 2015 and 2019. The SP remaining after outliers' removal accounted for more than 90% of the WW volume treated in TP and 95% of the DW volume treated in TP. The final data represents more than 200 DWTP, 660 million m^3 of collected water and around 4.2 million supplied households, and more than 2000 WWTP and around 9 million-person equivalents (p.e.), each year.

2.2. Potential drivers

Three types of potential drivers were analyzed: i) factors dependent on the SP size; ii) factors independent of the SP size; and iii) certification policy factors, presented in Table 2, as well as its descriptive statistics. The governance models were direct governance (1), public owned delegation (2) and concession (3) models, with all these models encompassing both municipal and intermunicipal SP (usually lower and higher aggregation levels, respectively). Both delegations and concessions present an entrepreneurial structure. The plant typologies included predominantly rural (1), moderately urban (2) and predominantly urban (3). Within quality, environmental, energy and occupational health and safety (OHS) certifications, two binary groups were considered (absence - 0 and presence - 1) for each certification type.

2.3. Statistical analysis

Cross-correlation analysis allows determining correlations between all pairs of variables in a given data set. In this study, the entire OI and potential drivers' dataset was analyzed, for the SP from both DW and WW sectors, in order to determine their intrinsic correlations and to

Table 1
– Mean and standard deviation of input and output OI.

		OI	Abbrev. and units	DW		WW	
				Mean	Deviation	Mean	Deviation
OI	Inputs	Energy consumption ***	EnC (GW/year)	10.9	28.7	2.9	13.4
		Allocated personnel ***	Personnel (p.e./year)	62.2	61.2	32.4	81.3
		Total expenditures **	Expenditures (M€/year)	11.2	22.2	4.6	16.2
		Intake DW or WW ***	Win (Mm^3/year)	18.0	44.5	5.8	25.3
	Outputs	Energy production ***	EnP (GW/year)	0.22	1.04	0.22	1.6
		Revenue DW or WW ***	RevW (Mm^3/year)	16.3	42.8	4.9	23.2
		Water losses ***	Wlos (Mm^3/year)	1.23	1.95	–	–
		Treated WW **	TWW (Mm^3/year)	–	–	4.8	24.4
		Reused WW **	RWW (Km^3/year)	–	–	58	349
		Sludge production ***	Sludge (Kton/year)	–	–	3.7	18.6

*, ** and *** represent the degree of reliability according to the RASARP (*** is the most reliable).

Table 2
– Mean and standard deviation of size dependent, size independent and certification policy factors.

	Potential drivers	Abbrev. and units	DW		WW	
			Mean	Deviation	Mean	Deviation
SDF	Number of DWTP ***	DWTP (#)	5.0	11.3	–	–
	Number of WWTP ***	WWTP (#)	–	–	17.7	49.9
	Number of other treatment facilities ***	Other_TP (#)	19.8	26.9	–	–
	Number of septic tanks ***	Septic_tanks (#)	–	–	8.1	13.8
	Number of pumping stations ***	Pumping_stations (#)	23.5	39.2	29.9	72.6
	Collected DW ***	Wcol (Mm^3/year)	16.7	44.6	–	–
	Number of supplied households ***	Households (#) [x10^{-5}]	1.02	2.42	0.39	1.65
	Effectively served population **	Serv_pop (p.e.) [x10^{-4}]	–	–	9.0	38.2
	Sewers total length ***	Sewers_length (km)	–	–	267	320
	Mains total length ***	Mains_length (km)	73.2	75.1	–	–
SIF	Mains rehabilitation ***	Mains_rehab (%)	0.49	0.63	–	–
	Sewers rehabilitation ***	Sewers_rehabl (%)	–	–	0.04	0.08
	Water supply failures **	Fail_DW (/branches.year)	0.50	1.40	–	–
	TP adequateness (served per dimensioning population) **	Adequateness (%)	–	–	47.1	60.8
	Safe water ***	Safe_DW (%)	99.2	1.0	–	–
	Discharge parameters compliance **	Compliance (%)	–	–	65.0	34.0
	Population with satisfactory treatment **	Satisf_treat (%)	–	–	64.2	35.7
	Governance model ***	Governance	1.75	0.89	1.45	0.77
	Plants typology ***	Typology	1.60	0.66	1.38	0.63
CPF	Environmental certification ***	Env_cert	0.26	0.44	0.16	0.36
	OHS certification ***	OHS_cert	0.25	0.44	–	–
	Quality certification ***	Qual_cert	0.47	0.50	0.27	0.45
	Energy certification ***	Ener_cert	0.10	0.30	0.04	0.19

SDF – Size dependent factors; SIF – Size independent factors; CPF – Certification policy factors; *, ** and *** represent the degree of reliability according to the RASARP.

establish dependency relationships (Einax et al., 1997). Cross-correlation values equal to, or above, 0.5 were set to select potential drivers. The use of cross-correlation analysis in the present study allowed to identify univocal (variable to variable) relationships within the collected data. This knowledge is fundamental, though it is not sufficient, to understand the underlying dependencies of the employed dataset and identify the main drivers for the considered OI. Microsoft Excel (Microsoft, Redmond, USA) was used for the cross-correlation analysis.

Hierarchical clustering analysis was performed to highlight the aggregation between the different variables, and the way in which they are hierarchically related. This analysis generated a dendrogram, encompassing the entire OI and potential drivers' dataset, for the SP from both DW and WW sectors, in the form of a hierarchical binary clustering tree. Each established link between variables is graphically (dendrogram) represented in a U form connecting data points (clusters) of the hierarchical tree, where its height represents the distance between the two connected data points (Einax et al., 1997). The use of the hierarchical clustering analysis in the present work allowed to determine the aggregation pattern of the studied data, both in terms of aggregation structure (ascending aggregation or prevalence of specific clusters) as well as to better identify correlation hierarchies. This analysis complemented, and expanded, the knowledge brought by the results obtained by the cross-correlation analysis, given that cross-correlation fails in correctly identifying variables clusters and hierarchies. Matlab R2014a (The Mathworks, Natick, USA) was used for the hierarchical clustering analysis. Single Euclidean distances were used in the present study and further represented in a dendrogram, with the X axis representing, from left to right, the cluster aggregation performed in each step, and the Y axis representing the (Euclidean) distance among the aggregated clusters in each step. Lower distance values represent better aggregation properties.

Principal components (PC) analysis reduces a set of high-dimensional and strongly correlated data, extracting the most relevant information about the new spaces generated by orthogonal vectors, called principal components, representing a linear combination of the original variables. Given that this technique aims to maximize the explained variance in each new orthogonal space, each new PC possesses a lower explanatory ability than the preceding ones. The importance of each initial variable (variable importance in projection – VIP) in the new PC represents the relative weight of the variable in the determination of the PC, implying that higher VIP means greater importance in its determination (Einax et al., 1997). The entire OI and potential drivers' dataset was analyzed, for the SP from both DW and WW sectors, in order to determine the importance of the studied variables for the establishment of orthogonal PC that best characterize, and synthesize, the range of SP operating conditions (Einax et al., 1997). PC analysis was implemented in the present work in order to identify the most important factors (or groups) characterizing, and synthesizing, the studied range of SP operating conditions. This, in turn, allows for further examining the results obtained by the former analyses, in terms of their overall standings with regard to the representation of the SP diversity. Matlab R2014a (The Mathworks, Natick, USA) was used for this analysis.

The use of cross-correlation, hierarchical clustering analysis and a PC analysis allowed for a holistic approach, complementing the conclusions that can be obtained from the use of each separate approach and shedding light to the main drivers' individual importance, aggregation patterns and overall stand in characterizing, and synthesizing, the range of SP operating conditions. As previously introduced, in addition to the analysis of the variables' absolute values, a study of OI and size dependent factors normalized by intake DW or WW volumes was also carried out. This second step aimed to minimize the influence that the SP size may have on the relationship between the other variables.

3. Results and discussion

3.1. Findings from original (absolute) data

The cross-correlation analysis results, addressing absolute values (i.e., not normalized by size) for all variables are presented in Tables 3 and 4. A high positive correlation between all OI was found, including inputs and outputs, except for the energy production in the DW sector. This is expected given that these variables are, for the most part, strongly dependent on the intake DW or WW volumes. The strong positive correlation between total expenditures, energy consumption and allocated personnel is also natural, given that two of the largest operating

Table 3
– Correlation coefficients (R) values for the studied variables, in absolute values, for DW SP.

			OI							SDF						SIF					CPF			
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
OI	1	EnC	1.00																					
	2	Personnel	0.87	1.00																				
	3	Expenditures	0.93	0.95	1.00																			
	4	Win	0.93	0.88	0.92	1.00																		
	5	EnP	0.02	0.01	0.02	0.04	1.00																	
	6	RevW	0.94	0.88	0.92	1.00	0.04	1.00																
	7	Wlos	0.70	0.74	0.71	0.84	0.01	0.82	1.00															
SDF	8	DWTP	0.47	0.57	0.60	0.38	−0.04	0.38	0.31	1.00														
	9	Other_TP	0.11	0.19	0.20	0.11	0.47	0.10	0.20	0.50	1.00													
	10	Pumping_stations	0.75	0.81	0.83	0.65	−0.05	0.65	0.53	0.78	0.35	1.00												
	11	Wcol	0.93	0.84	0.89	0.99	0.04	0.99	0.82	0.33	0.08	0.59	1.00											
	12	Households	0.98	0.90	0.96	0.94	0.04	0.95	0.70	0.50	0.13	0.77	0.93	1.00										
	13	Mains_length	0.53	0.75	0.66	0.47	−0.02	0.46	0.51	0.63	0.34	0.86	0.39	0.56	1.00									
SIF	14	Mains_rehab	−0.19	−0.17	−0.18	−0.19	0.18	−0.19	−0.10	0.01	0.26	−0.11	−0.19	−0.21	−0.05	1.00								
	15	Fail_DW	−0.10	−0.11	−0.09	−0.10	−0.08	−0.10	−0.03	−0.07	−0.06	−0.05	−0.12	−0.11	−0.04	0.05	1.00							
	16	Safe_DW	0.21	0.33	0.27	0.23	0.03	0.23	0.19	0.12	−0.18	0.24	0.21	0.24	0.29	−0.15	0.05	1.00						
	17	Governance	0.32	0.42	0.44	0.33	−0.05	0.33	0.10	0.25	−0.08	0.34	0.29	0.39	0.32	−0.26	−0.17	0.35	1.00					
	18	Typology	0.33	0.53	0.41	0.41	−0.10	0.41	0.45	0.04	−0.21	0.22	0.38	0.36	0.33	−0.22	0.04	0.41	0.40	1.00				
CPF	19	Env_cert	0.49	0.62	0.62	0.54	−0.02	0.55	0.35	0.28	−0.06	0.42	0.50	0.54	0.33	−0.23	−0.12	0.36	0.61	0.66	1.00			
	20	OHS_cert	0.50	0.62	0.63	0.55	−0.02	0.55	0.35	0.29	−0.06	0.42	0.51	0.55	0.33	−0.24	−0.11	0.35	0.61	0.66	0.99	1.00		
	21	Qual_cert	0.31	0.35	0.37	0.34	0.22	0.34	0.14	0.13	0.02	0.22	0.32	0.35	0.12	−0.04	−0.22	0.20	0.39	0.44	0.62	0.62	1.00	
	22	Ener_cert	0.77	0.73	0.77	0.78	−0.01	0.78	0.65	0.45	0.18	0.67	0.74	0.79	0.53	−0.13	−0.11	0.19	0.32	0.32	0.48	0.45	0.28	1.00

OI – Operational indicators; SDF – Size dependent factors; SIF – Size independent factors; CPF – Certification policy factors.

Table 4

– Correlation coefficient (R) values for the studied variables, in absolute values, for WW SP.

			OI									SDF						SIF						CPF		
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
OI	1	EnC	1.00																							
	2	Personnel	0.95	1.00																						
	3	Expenditures	0.97	0.94	1.00																					
	4	Win	0.98	0.93	0.96	1.00																				
	5	TWW	0.98	0.93	0.95	1.00	1.00																			
	6	RevW	0.98	0.92	0.95	1.00	1.00	1.00																		
	7	EnP	0.94	0.86	0.91	0.96	0.96	0.97	1.00																	
	8	RWW	0.94	0.92	0.92	0.94	0.95	0.95	0.89	1.00																
	9	Sludge	0.98	0.93	0.95	0.98	0.99	0.99	0.95	0.96	1.00															
SDF	10	WWTP	0.93	0.87	0.91	0.94	0.94	0.94	0.90	0.92	0.94	1.00														
	11	Septic_tanks	0.01	−0.02	0.02	0.03	0.03	0.03	0.04	0.03	0.03	0.09	1.00													
	12	Pumping_stations	0.93	0.92	0.93	0.91	0.91	0.90	0.85	0.88	0.90	0.90	−0.03	1.00												
	13	Households	0.99	0.94	0.96	0.99	0.99	0.99	0.96	0.96	0.99	0.95	0.03	0.92	1.00											
	14	Serv_pop	0.98	0.95	0.95	0.99	0.99	0.99	0.95	0.95	0.99	0.93	0.03	0.91	0.99	1.00										
	15	Sewers_length	0.72	0.80	0.77	0.71	0.69	0.68	0.63	0.63	0.68	0.66	0.00	0.81	0.71	0.72	1.00									
SIF	16	Sewers_rehab	−0.01	−0.01	−0.01	−0.01	−0.01	−0.01	−0.01	−0.01	−0.01	−0.01	0.00	−0.01	−0.01	−0.01	−0.01	1.00								
	17	Adequateness	0.05	0.05	0.04	0.04	0.05	0.04	0.03	0.04	0.04	0.02	−0.06	0.03	0.04	0.02	0.04	0.03	1.00							
	18	Compliance	0.38	0.41	0.36	0.37	0.37	0.36	0.36	0.34	0.38	0.33	−0.05	0.41	0.36	0.37	0.42	−0.03	−0.21	1.00						
	19	Satisf_treat	0.19	0.25	0.20	0.18	0.18	0.17	0.14	0.16	0.18	0.14	−0.08	0.25	0.18	0.19	0.32	−0.08	−0.28	0.88	1.00					
	20	Governance	0.35	0.40	0.38	0.34	0.33	0.32	0.26	0.30	0.33	0.25	−0.02	0.42	0.33	0.35	0.46	−0.03	0.04	0.42	0.39	1.00				
	21	Typololgy	0.34	0.50	0.37	0.33	0.32	0.31	0.27	0.28	0.33	0.20	−0.19	0.39	0.34	0.37	0.60	−0.03	0.04	0.39	0.36	0.52	1.00			
CPF	22	Qual_cert	0.27	0.33	0.30	0.27	0.26	0.26	0.23	0.25	0.25	0.24	−0.02	0.33	0.27	0.28	0.35	−0.03	0.04	0.29	0.27	0.49	0.35	1.00		
	23	Env_cert	0.39	0.45	0.42	0.38	0.37	0.36	0.32	0.36	0.35	0.30	−0.11	0.42	0.38	0.39	0.48	−0.02	0.04	0.30	0.27	0.61	0.46	0.70	1.00	
	24	Ener_cert	0.60	0.55	0.57	0.61	0.59	0.61	0.62	0.49	0.56	0.50	−0.04	0.51	0.59	0.62	0.40	−0.01	0.04	0.25	0.16	0.30	0.22	0.30	0.43	1.00

OI – Operational indicators; SDF – Size dependent factors; SIF – Size independent factors; CPF – Certification policy factors.

expenditures usually relate to these factors.

It should be noticed, however, that energy production in the DW sector is not directly dependent on the volume of intake DW, but rather an option for the SP. This can explain why it is not correlated with the other OI. On the other hand, although the same principle, in abstract, can be applied to the WW sector, a high positive correlation between energy production and the other OI was found in this case. This can be explained by the larger potential for energy production in the WW sector, arising from the use of anaerobic treatment systems with biogas generation or aerobic systems by incinerating dehydrated sludge. Hence, the volume of treated WW is relevant for the SP energy production potential, as demonstrated by the cross-correlation analysis.

The majority of size dependent factors presents a high positive correlation with the OI (except for energy production in the DW sector), as would be expected, since the largest SP process, as a rule, larger intake DW or WW volumes. Also noticeable is the high positive correlations obtained for the number of supplied households (DW and WW) and served population (WW), as well as for the number of WWTP and pumping stations (WW). On the other hand, the number of treatment facilities other than DWTP (DW) and of septic tanks (WW) do not seem to be correlated with the OI. It is also noteworthy to point out that larger correlations were obtained for the size dependent factors with input OI rather than output OI.

Not surprisingly, several significant correlations are observed among the size dependent factors. In the DW sector, positive correlations were obtained between the number of supplied households and the collected water volumes, on one hand, and the number of pumping stations with the mains length and number of DWTP, on the other. Concerning the WW sector, and except for a single variable, all the remaining were positively correlated with each other. In this regard, the positive correlations obtained between the served population and number of supplied households, pumping stations and WWTP should be highlighted. Also noteworthy is the fact that the number of treatment facilities other than DWTP (DW) and the number of septic tanks (WW) were not correlated with the other size dependent factors.

With respect to the size independent factors, no significant correlation was found with the OI, both for the DW and the WW sectors. Additionally, these variables were not correlated with the size dependent factors, except for SP typology (incrementally from predominantly rural, moderately urban and predominantly urban) with allocated personnel (DW and WW) and sewers' length (WW), nor with each other (except for the positive correlation between the TP adequateness and discharge compliance, and of SP typology with the governance model in WW). However, it should be stressed that the subsequent analysis performed with the normalized data did not confirm the SP typology as an actual driver for allocated personnel or sewer's length. Indeed, in both cases a slightly negative correlation was found regarding the normalized values. That being the case, the positive correlation observed for the absolute values may be due to the SP typology (incrementally from predominantly rural, moderately urban and predominantly urban) being correlated positively with the SP size, similar to the allocated personnel and sewer's length.

The governance model (incrementally from direct governance, public owned delegation and concession) and the SP typology (incrementally from predominantly rural, moderately urban and predominantly urban) correlated positively with the presence of environmental and OHS certifications (with stronger correlations for DW, compared to WW). These findings were further confirmed by the subsequent clustering analysis. Hence, the SP with such certifications were mostly related to concession, followed by public owned delegation. In the same way, these SP were also mostly related to predominantly urban, followed by moderately urban typologies. However, it is not clear if the correlations found are, in fact, due to the governance model and SP typology focus on pursuing such policies, or rather an indirect consequence of SP size dependence. Indeed, the certification policy was found to be well correlated with SP size, as well as governance model and SP typology to a lower degree.

In the Portuguese case, the main differences between the three models are the following: i) Concessions are private operators who have won municipal concession tenders for the right to operate the water systems and are in charge of providing the service; ii) Public owned delegations are municipal or inter-municipal companies (in most cases) and state-municipal partnerships; and iii) Direct management are councils and municipal services. Both concessions and public owned delegations are corporate services, with private or public capital, but autonomous and managed in an entrepreneurial way. In the concession model, the municipalities authorize contracts with private companies, setting the respective general conditions. Regarding public owned delegations and direct management, the right of exploitation remains within the public sector.

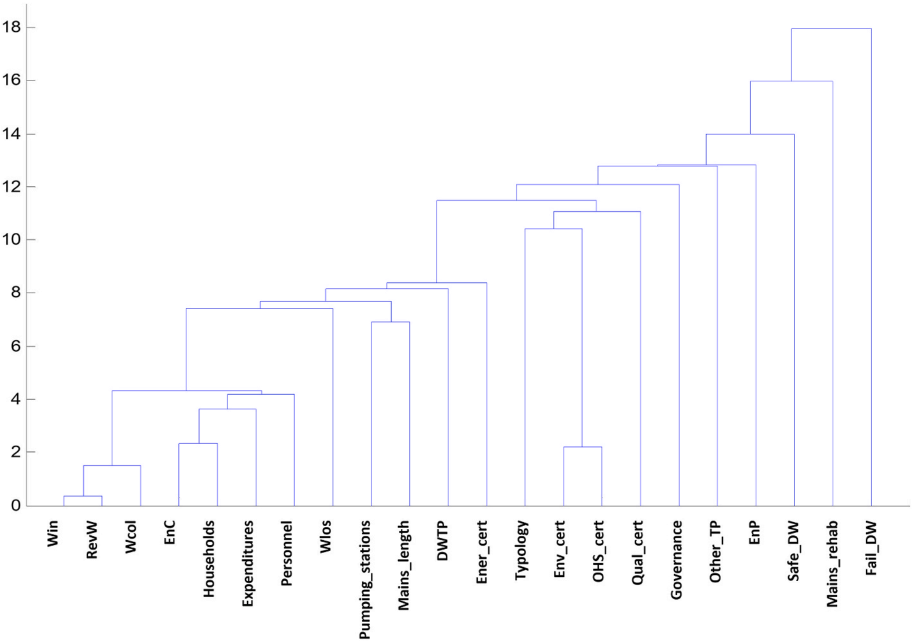

Fig. 1. – Hierarchical clustering analysis of the studied variables, in absolute values, for DW SP.

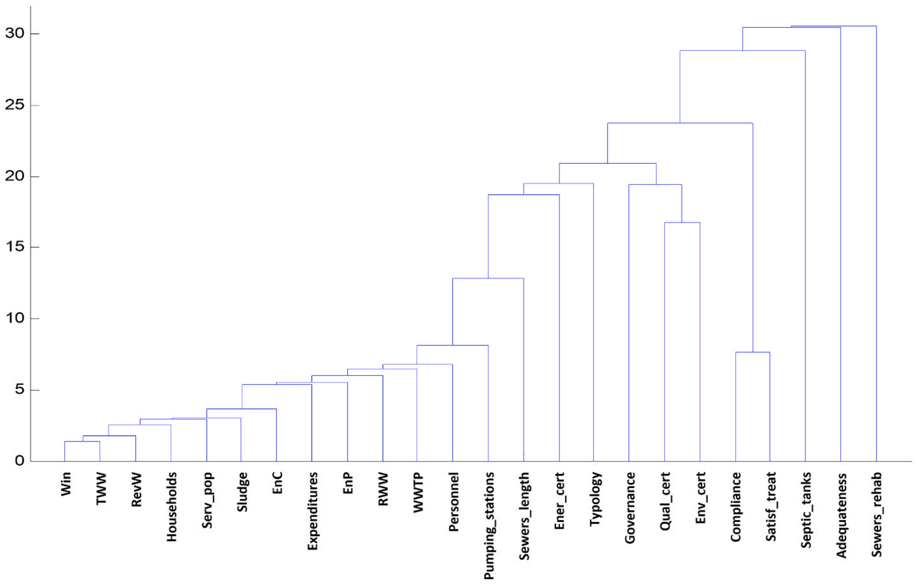

Fig. 2. – Hierarchical clustering analysis of the studied variables, in absolute values, for WW SP.

Energy certification proved to be the certification policy factor most correlated (positively) with OI (except for energy production in DW), both for the DW and WW sectors. In the WW sector, it was the sole certification with a significant and positive correlation with the OI, whereas in the DW sector, the presence of environmental and OHS certifications can be considered relevant as well. The presence of certifications is also, in general, more strongly correlated with input OI in the DW sector, when compared with the WW sector. Furthermore, the subsequent analysis performed with the normalized data allowed to dismiss the certification policy (including energy) as an actual driver given the mostly negative correlations found. Hence, the obtained results could be related to energy consumption being one of the most important costs contributing to total expenditures and, therefore, energy certification policies being pursued by the SP that present larger total expenditures (in order to reduce the associated costs). In fact, the analysis performed with the normalized data seems to highlight the importance of the energy certification policy in increasing normalized energy production.

Similar to the OI analysis, energy certification was the most (positively) correlated certification policy factor with the size dependent factors, standing out the correlations obtained with the number of supplied households and served population in the WW sector and collected water and number of households in the DW sector. This fact comes in agreement with the previous assumption that larger SP (presenting larger expenditures) recognize the importance of implementing certification policies (with an emphasis on sustainable energy practices).

In the DW sector, a strong positive correlation could be found between the presence of environmental and OHS certifications, and of both with quality certification (to a lesser degree). Regarding the WW sector, the positive correlation between environmental and quality certifications stands out. These results reveal that the SP engaged in certification policies are more likely to group quality, environmental and OHS certifications together whereas energy certification stands somewhat independent from the prior. These findings were further confirmed by the

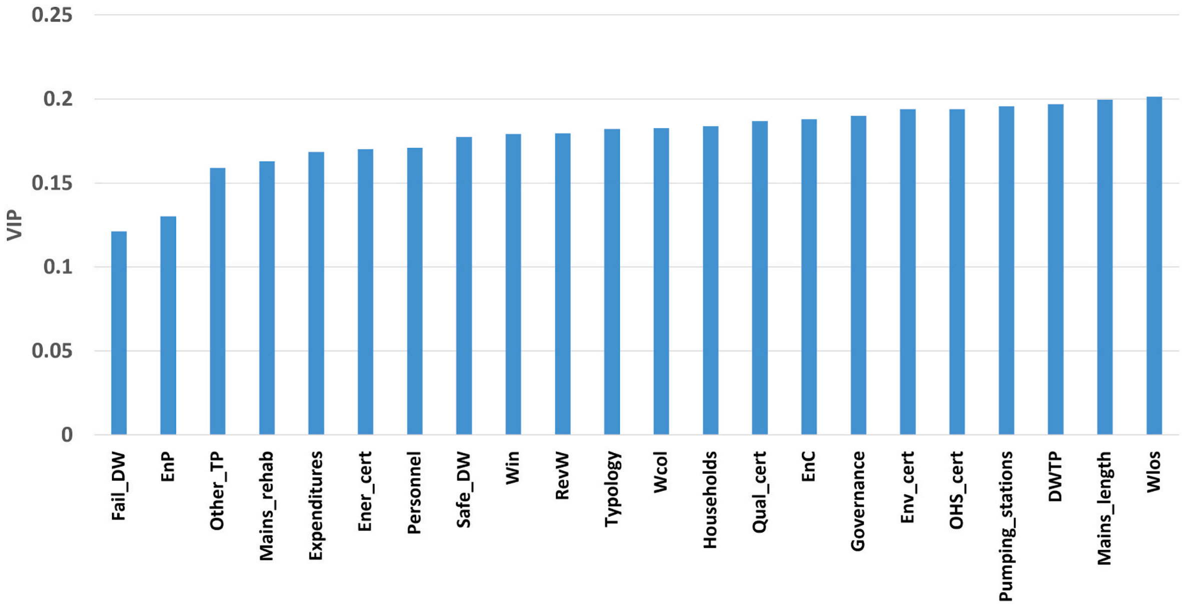

Fig. 3. – VIP (PC analysis) of the studied variables, in absolute values, for DW SP.

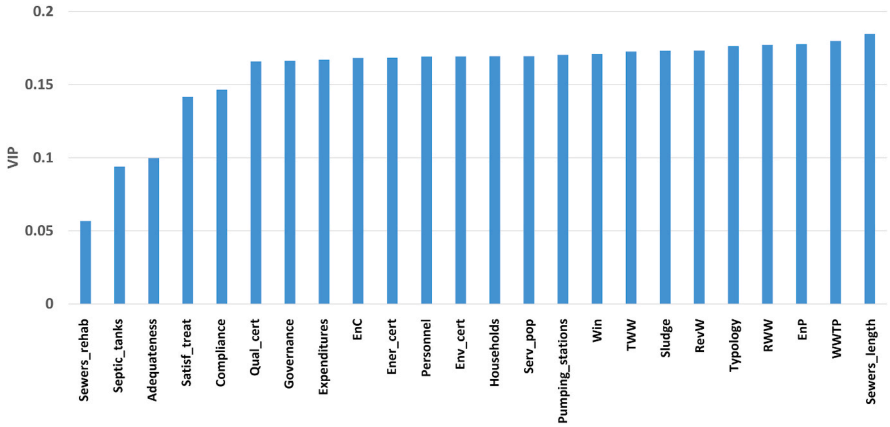

Fig. 4. – VIP (PC analysis) of the studied variables, in absolute values, for WW SP.

subsequent clustering analysis.

Still addressing absolute values, the use of a hierarchical clustering technique, represented in Figs. 1 and 2, allowed to highlight the hierarchical aggregation among the different variables. In the DW sector, the highest degree of aggregation was obtained for the volumes of intake, revenue and collected DW volumes, closely related to each other, corroborating the previous cross-correlation analysis. A second level of aggregation encompasses input OI, namely the energy consumption, total expenditures and allocated personnel, related to each other and to the number of supplied households. Likewise, these variables had already been shown to correlate well among each other. It was also possible to confirm a certain degree of aggregation between the number of pumping stations and the mains length, as well as with the number of DWTP, water losses volume and the presence of energy certification to a lesser extent. Again, corroborating the previous cross-correlation analysis, it was also possible to verify a high degree of aggregation between the environmental and OHS certifications, as well as with the DW typology and quality certification to a lesser extent.

In the WW sector, an ascending level of aggregation prevailed over the existence of specific clusters. A first level of aggregation encompasses intake, treated and revenue WW volumes, number of supplied households and population, energy consumption and even sludge production. A second level of aggregation encompasses total expenditures, energy production, reused WW volume, number of WWTP and pumping stations, and allocated personnel. Sewers' length, presence of energy certification and SP typology further presents some degree of aggregation. Cluster-wise, and at different levels of aggregation, compliance with discharge parameters gather with the percentage of population with satisfactory treatment, whereas environmental and quality certifications aggregate among each other as well as with the governance model. Again, the clustering analysis is well aligned with the results from the previous cross-correlation analysis.

Globally, the performed hierarchical clustering analysis points out the aggregation of: i) OI with size dependent factors and within each other (except for energy production in DW); ii) environmental, OHS (and even quality) certifications; and iii) SP typology, governance model and certifications policy (including energy certification), to a lesser extent.

Finally, a PC analysis allowed to determine the most important factors (higher VIP values) for the establishment of the set of orthogonal PC (Figs. 3 and 4) characterizing, and synthesizing, the range of SP operating conditions. The relevance of size dependent factors is stressed in the DW sector (average VIP of 0.186, mainly mains length and number of DWTP and pumping stations) and certification policy factors (average VIP of 0.186, mainly environmental, OHS and quality certifications), followed by input OI (average VIP of 0.177, mainly energy consumption and intake DW volume). Lower average VIP were obtained by size independent factors (average VIP of 0.167, with the governance model and SP typology assuming some relevance) and output OI (average VIP of 0.17, with the water losses and revenue DW volumes assuming some relevance).

Concerning the WW sector, output OI (average VIP of 0.175, mainly energy and sludge production, and reused, treated and revenue WW volumes) contributed the most to the main PC found. Also of significant importance were input OI (average VIP of 0.169, mainly intake WW volumes, allocated personnel, energy consumption and total expenditures), certification policy factors (average VIP of 0.168, mainly environmental and energy certifications) and size dependent factors (average VIP of 0.161, mainly length of sewers, number of WWTP and pumping stations, and supplied households and population). Lower average VIP were obtained by size independent factors (average VIP of 0.131, with the governance model and SP typology assuming some relevance).

3.2. *Findings from normalized data*

The results from a second cross-correlation analysis carried out with normalized OI and size dependent factors (by intake DW or WW volumes) are presented in Tables 5 and 6. In the DW sector solely normalized water losses and revenue DW volumes (negative correlation) on one hand and normalized total expenditures and allocated personnel on the other (positive correlation), presented relevant correlations. Concerning the WW sector, the positive correlations obtained between the revenue WW volume, allocated personnel and total expenditures can be highlighted.

The negative correlation obtained between normalized water losses and revenue DW volumes should be expected, given that the treated DW escaping from mains upstream the supplied households represents a cost without the corresponding revenue. Again, it was also possible to observe the preponderant role of normalized allocated personnel (one of the largest operating expenditures) to normalized total expenditures for both DW and WW sectors. This result complements the cross-correlation analysis performed with absolute values where the total expenditures were strongly correlated with the allocated personnel and energy consumption. Both for the DW and WW sectors, the normalized total expenditures are more dependent (correlated) on the allocated personnel, maintaining a lower dependence on the intake DW or WW volumes (smaller variation in absolute terms) than with energy consumption (larger variation). This trend is more marked for the DW sector rather than for the WW sector.

Addressing the DW sector, the correlations of the normalized revenue DW (positive correlation) and water losses (negative correlation) with the governance model (incrementally from governance direct, public owned delegation and concession) and environmental and OHS

Table 5
– Correlation coefficient (R) values for the studied variables, in normalized values, for DW SP.

			OI						SDF						SIF					CPF			
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
OI	1	EnC/m^3	1.00																				
	2	Personnel/m^3	0.11	1.00																			
	3	Expenditures/m^3	−0.12	0.55	1.00																		
	4	EnP/m^3	−0.14	−0.11	−0.20	1.00																	
	5	RevW/m^3	−0.14	−0.25	0.22	−0.19	1.00																
	6	Wlos/m^3	0.18	0.29	−0.16	0.03	−0.89	1.00															
SDF	7	DWTP/m^3	0.31	0.51	0.06	−0.10	−0.45	0.48	1.00														
	8	Other_TP/m^3	0.07	0.41	−0.02	0.17	−0.31	0.29	0.44	1.00													
	9	Pumping_stations/m^3	0.47	0.33	0.19	−0.16	−0.22	0.25	0.33	0.21	1.00												
	10	Wcol/m^3	0.50	−0.08	−0.44	0.09	0.00	0.00	0.09	0.19	0.14	1.00											
	11	Households/m^3	−0.01	0.33	0.42	−0.05	0.25	−0.26	0.03	0.17	0.08	0.01	1.00										
	12	Mains_length/m^3	0.28	0.68	0.43	−0.07	−0.33	0.36	0.36	0.41	0.50	0.09	0.31	1.00									
SIF	13	Mains_rehab	−0.01	0.01	0.03	0.22	−0.16	0.07	0.20	0.16	0.25	−0.11	−0.19	0.10	1.00								
	14	Fail_DW	0.22	−0.15	−0.05	−0.06	−0.21	0.15	−0.01	−0.10	0.04	−0.24	−0.21	−0.03	0.05	1.00							
	15	Safe_DW	−0.06	−0.26	0.10	−0.01	0.36	−0.39	−0.33	−0.51	−0.19	−0.01	0.10	−0.34	−0.15	0.05	1.00						
	16	Governance	−0.24	−0.14	0.31	−0.12	0.65	−0.59	−0.32	−0.27	−0.35	0.03	0.44	−0.16	−0.26	−0.17	0.35	1.00					
	17	Typololgy	−0.30	−0.31	0.04	−0.14	0.46	−0.39	−0.45	−0.39	−0.48	−0.29	−0.10	−0.55	−0.22	0.04	0.41	0.40	1.00				
CPF	18	Env_cert	−0.23	−0.32	0.19	−0.09	0.59	−0.51	−0.33	−0.29	−0.38	−0.17	0.05	−0.46	−0.23	−0.12	0.36	0.61	0.66	1.00			
	19	OHS_cert	−0.22	−0.32	0.19	−0.09	0.59	−0.51	−0.32	−0.30	−0.38	−0.16	0.05	−0.46	−0.24	−0.11	0.35	0.61	0.66	0.99	1.00		
	20	Qual_cert	−0.03	−0.22	0.08	0.17	0.41	−0.38	−0.18	−0.17	−0.12	0.05	0.16	−0.38	−0.04	−0.22	0.20	0.39	0.44	0.62	0.62	1.00	
	21	Ener_cert	−0.08	−0.36	−0.21	−0.05	0.37	−0.31	−0.23	−0.15	−0.27	0.07	−0.07	−0.32	−0.13	−0.11	0.19	0.32	0.32	0.48	0.45	0.28	1.00

OI – Operational indicators; SDF – Size dependent factors; SIF – Size independent factors; CPF – Certification policy factors.

certifications stands out. This is further reinforced by the clustering analysis with respect to normalized revenue DW. It should also be kept in mind that a decrease in water losses allows for a larger quantity of DW to be delivered and represent a revenue for the SP. This suggests that the SP (mainly with concession or public owned delegation models) that implement a certification policy (particularly environmental and OHS certifications) are able to minimize water losses and obtain gains in revenue water.

In the WW sector, the normalized allocated personnel, total expenditures and revenue WW volume are positively correlated with the normalized sewer's length, number of supplied households and WWTP, and pumping stations (to a lesser extent). Hence, it can be considered that these drivers (and mainly the first two) are relevant in the SP demand for allocated personnel, total expenditures and revenue WW volume. Not surprisingly, all of the above drivers were found to be positively correlated with each other. One can expect that a larger normalized (per water intake) number of supplied households has the potential to generate higher normalized volumes of revenue WW. However, as the obtained correlation value (0.97) emphatically demonstrates, this translates into a larger normalized (per water intake) sewer network. That being the case, and considering the rise on related pumping stations (as confirmed by the obtained correlation), it implicates an increased effort (both in personnel and in costs) comparing to more compact sewerage systems. Higher normalized personnel and expenditure values were also obtained for larger normalized numbers of WWTP (representing smaller TP with respect to water intake), inciting the use of a lower number of larger WWTP rather than a higher number of smaller WWTP.

On the other hand, no significant correlations were found between the normalized size dependent factors among each other or with the size independent factors and certification policy factors, except for a negative correlation between the SP typology (incrementally from predominantly rural, moderately urban and predominantly urban) and the mains length, for the DW sector. This is in accordance with the assumption that, in rural areas with a lower population density, a more extensive DW distribution network will be necessary. Furthermore, and although not definitive, the effect of energy certification policies on normalized energy production may also be inferred, by the obtained positive correlation.

The results from the hierarchical clustering analysis, with regard to the normalized variables, are presented in Figs. 5 and 6. In the DW sector, the highest degree of aggregation occurred between environmental and OHS certifications, and to a lesser extent with the SP typology, quality certification, normalized revenue DW volume and governance model, corroborating the previous cross-correlation analysis. To a much lesser extent, some aggregation occurred between this cluster and the normalized number of supplied households, energy certification and safe water. A second cluster could be observed, although with a lower level of aggregation, encompassing the normalized allocated personnel, mains length, total expenditures, number of pumping stations and, to a lesser extent, with normalized energy consumption and collected DW volume, as well as with the normalized number of DWTP and water losses volume. Again, the clustering analysis is well aligned with the results from the previous cross-correlation analysis.

Addressing the WW sector, a first level of ascending aggregation was visible, although without the formation of a true cluster, encompassing the normalized revenue DW volume, number of supplied households, sewers' length, total expenditures, allocated personnel and even the normalized number of WWTP and pumping stations. Based on the previous cross-correlation analysis this aggregation is not surprising. A possible second cluster, although with a significantly lower level of aggregation, aggregated the normalized treated WW volume, served population, energy consumption and sludge production. A certain degree of aggregation could also be observed between the compliance with discharge parameters and the percentage of population with satisfactory

Table 6

– Correlation coefficient (R) values for the studied variables, in normalized values, for WW SP.

			OI								SDF						SIF						CPF		
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
OI	1	EnC/m^3	1.00																						
	2	Personnel/m^3	0.29	1.00																					
	3	Expenditures/m^3	0.40	0.85	1.00																				
	4	TWW/m^3	0.49	0.13	0.08	1.00																			
	5	RevW/m^3	0.25	0.92	0.89	0.10	1.00																		
	6	EnP/m^3	0.08	−0.06	−0.05	0.27	−0.01	1.00																	
	7	RWW/m^3	0.17	−0.09	−0.06	0.36	−0.03	0.36	1.00																
	8	Sludge/m^3	0.15	−0.01	−0.01	0.08	0.00	0.00	0.01	1.00															
SDF	9	WWTP/m^3	0.43	0.65	0.69	0.20	0.55	−0.10	−0.14	0.03	1.00														
	10	Septic_tanks/m^3	−0.04	0.19	0.07	0.05	0.09	−0.08	−0.12	−0.01	0.14	1.00													
	11	Pumping_stations/m^3	0.50	0.51	0.64	0.04	0.46	−0.09	−0.10	−0.01	0.58	0.02	1.00												
	12	Households/m^3	0.26	0.91	0.89	0.09	0.98	−0.03	−0.05	0.00	0.60	0.13	0.48	1.00											
	13	Serv_pop/m^3	0.38	0.15	0.05	0.53	0.06	0.17	0.28	−0.02	0.17	0.08	0.05	0.06	1.00										
	14	Sewers_length/m^3	0.32	0.90	0.93	0.10	0.94	−0.07	−0.07	0.01	0.68	0.16	0.57	0.97	0.08	1.00									
SIF	15	Sewers_rehab	−0.02	−0.01	−0.01	−0.04	−0.02	−0.01	−0.01	0.00	−0.02	−0.01	−0.01	0.00	0.01	−0.01	1.00								
	16	Adequateness	0.02	−0.03	−0.04	0.05	−0.01	0.03	0.08	−0.03	−0.02	−0.05	−0.07	−0.01	0.37	−0.03	0.03	1.00							
	17	Compliance	0.19	−0.13	−0.09	0.34	−0.03	0.25	0.28	0.29	−0.19	−0.11	−0.06	−0.06	0.01	−0.09	−0.03	−0.21	1.00						
	18	Satisf_treat	0.19	−0.10	−0.07	0.32	−0.01	0.21	0.26	0.29	−0.16	−0.11	−0.05	−0.03	−0.04	−0.06	−0.08	−0.28	0.88	1.00					
	19	Governance	0.12	0.00	0.06	0.30	0.12	0.24	0.28	0.00	−0.16	−0.04	−0.08	0.10	0.18	0.05	−0.03	0.04	0.42	0.39	1.00				
	20	Typololgy	0.10	−0.15	−0.09	0.29	−0.05	0.41	0.36	0.00	−0.29	−0.23	−0.19	−0.09	0.17	−0.15	−0.03	0.04	0.39	0.36	0.52	1.00			
CPF	21	Qual_cert	0.04	0.00	0.06	0.24	0.09	0.26	0.25	−0.02	−0.04	−0.14	−0.08	0.08	0.10	0.04	−0.03	0.04	0.29	0.27	0.49	0.35	1.00		
	22	Env_cert	0.08	0.04	0.09	0.23	0.15	0.31	0.37	−0.01	−0.05	−0.15	−0.05	0.13	0.12	0.08	−0.02	0.04	0.30	0.27	0.61	0.46	0.70	1.00	
	23	Ener_cert	0.03	−0.08	−0.05	0.13	0.00	0.46	0.16	0.00	−0.10	−0.08	−0.08	−0.04	0.08	−0.06	−0.01	0.04	0.25	0.16	0.30	0.22	0.30	0.43	1.00

OI – Operational indicators; SDF – Size dependent factors; SIF – Size independent factors; CPF – Certification policy factors.

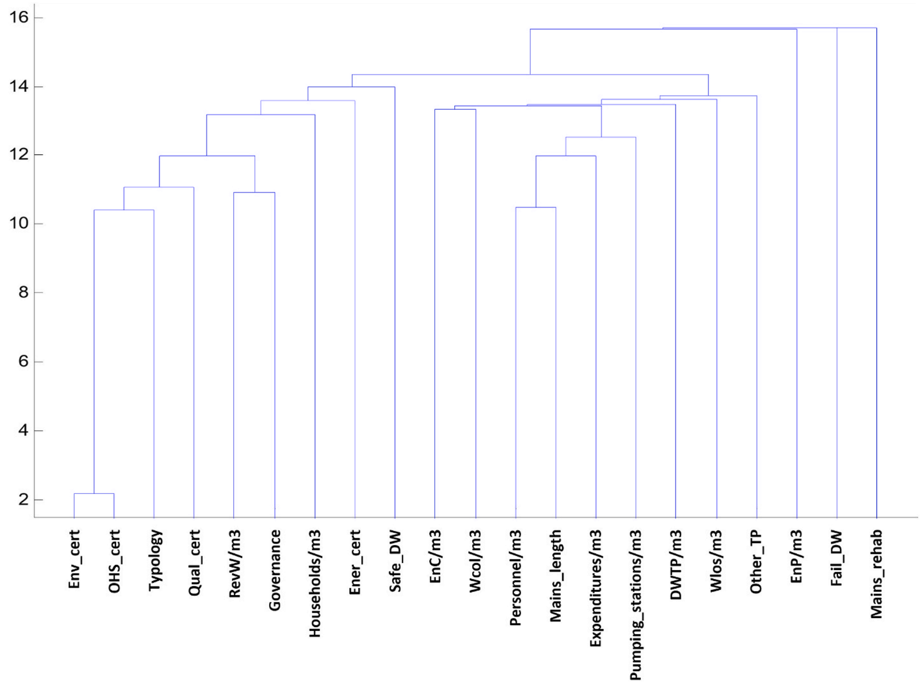

Fig. 5. – Hierarchical clustering analysis of the studied variables, in normalized values, for DW SP.

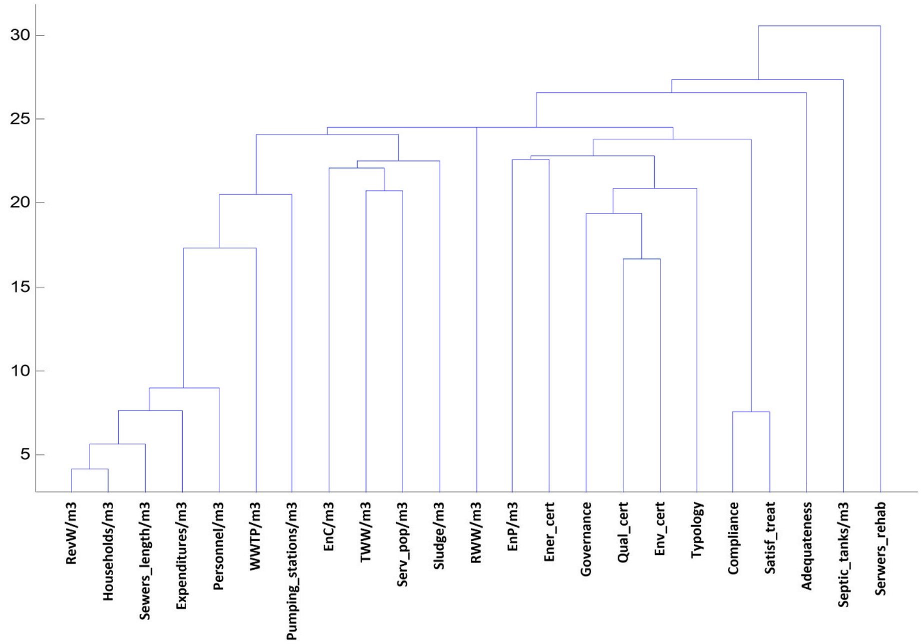

Fig. 6. – Hierarchical clustering analysis of the studied variables, in normalized values, for WW SP.

treatment, between environmental and quality certifications, governance model and SP typology, and even between the normalized energy production and energy certification, relatively similar to the DW sector.

Globally, the hierarchical clustering analysis points out the aggregation of: i) size dependent factors with input OI and most of output OI; ii) certification policy factors with energy production (WW) and revenue DW volume (DW); and iii) governance model, SP typology and certifications policy.

The main results obtained by PC analysis with the normalized variables are presented in Figs. 7 and 8. With regard to the DW sector, one can stress the relevance of output OI (average VIP of 0.191, mainly normalized water losses and revenue DW volumes) and certification policy factors (average VIP of 0.185, mainly energy and quality certifications). These are followed by size independent factors (average VIP of 0.177, mainly governance model, safe water and SP typology) and size dependent factors (average VIP of 0.176, mainly the normalized number of pumping stations, DWTP and other treatment facilities and mains length). Lower average VIP were obtained by input OI (average VIP of 0.164, with the normalized allocated personnel and energy consumption assuming some relevance).

Concerning the WW sector, certification policy factors (average VIP of 0.166, mainly energy and quality certifications) presented the highest relevance, followed by output OI (average VIP of 0.157, mainly normalized sludge and energy production, reused and revenue WW

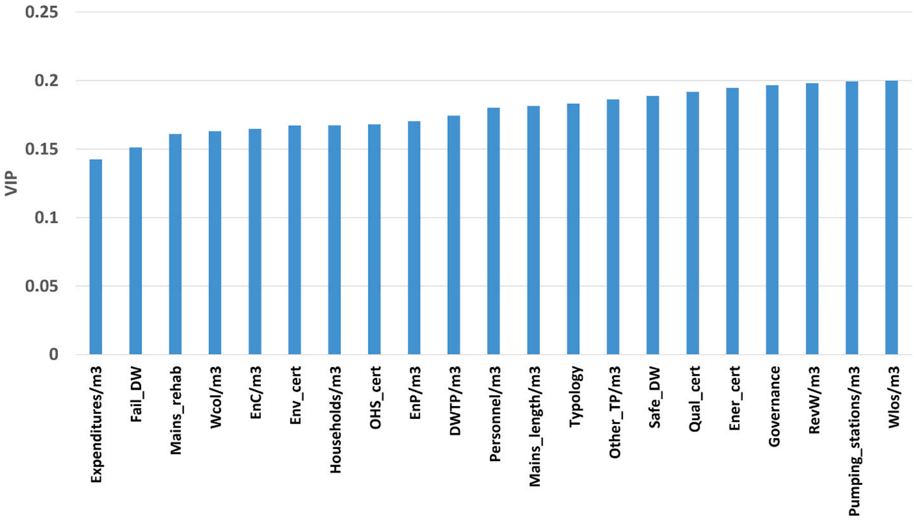

Fig. 7. – VIP (PC analysis) of the studied variables, in normalized values, in the DW SP.

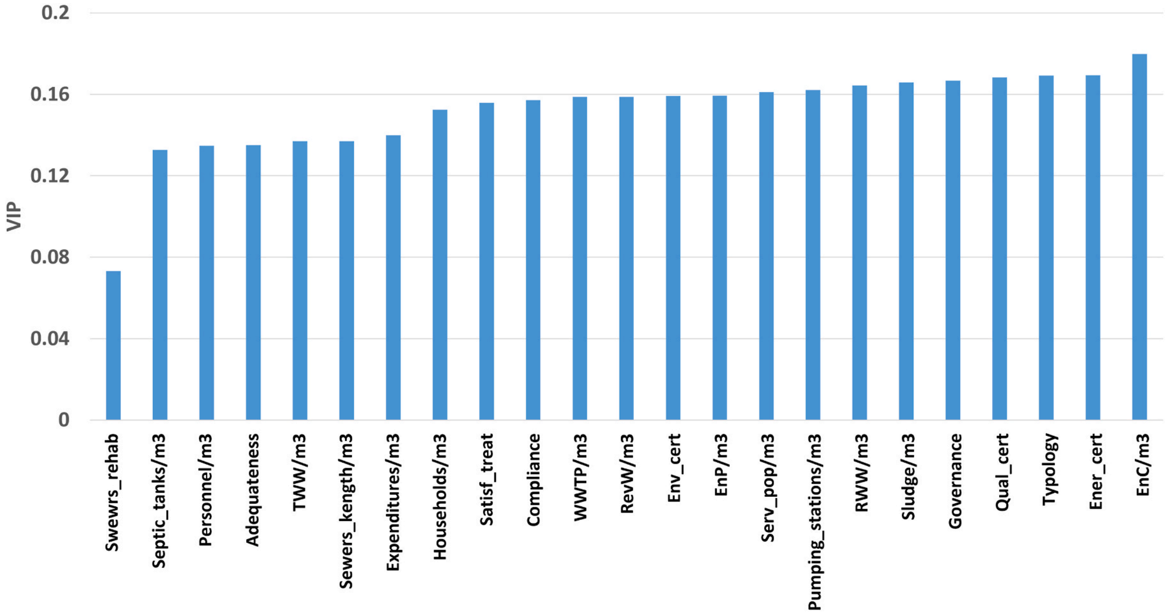

Fig. 8. – VIP (PC analysis) of the studied variables, in normalized values, in the WW SP.

volumes), input OI (average VIP of 0.151, mainly normalized energy consumption), and size dependent factors (average VIP of 0.151, mainly normalized number of LF, WWTP, supplied households and population). Lower average VIP were obtained for the size independent factors (average VIP of 0.143, with the governance model and SP typology assuming some relevance).

4. Conclusions

The importance of the SP size to the input and output operational indicators was evidenced by the high (and positive) correlations obtained with the size dependent factors, particularly the number of supplied households and served population. Solely energy production was found to be somewhat independent of SP size in the DW sector. On the other hand, the larger SP in the WW sector showed an increased potential for energy production. In this regard, energy certified SP presented an increased energy production. The results also allow highlighting the essential role that the largest SP seem to attribute to certification policies, and particularly to energy certification. Furthermore, SP presenting environmental and OHS certifications were found to be mostly related to predominantly urban, followed by moderately urban, rather than predominantly rural typologies. These SP were also mostly concessions, followed by public owned delegations, rather than direct management governance models.

Through the use of normalized (by intake DW or WW) data it was possible to identify the influence of water losses on revenue DW, which may derive from the fact that treated DW escaping from mains upstream represents a cost without the corresponding revenue. It was also possible to observe the preponderant role of allocated personnel (one of the largest operating expenditures) in total expenditures for both DW and WW sectors. The governance model (incrementally from direct governance, public owned delegation and concession) and the presence of environmental and OHS certifications had a clear positive effect on the revenue DW, and a negative effect on water losses. This suggests that the SP that pursue a certification policy (mainly within concession or public owned delegation models), effectively implementing such practices in the field, are more capable of minimizing water losses and, therefore, increase revenues. SP typology was found to influence mains length, as in rural areas, with lower population densities, a more extensive DW distribution network is necessary for equal intake volumes.

Sewer's length and number of supplied households were shown to influence the SP's personnel and expenditures needs as well as revenue WW volumes in the WW sector. Indeed, an increase on the number of supplied households, per water intake, has the potential to generate higher revenues, with the trade-off of larger sewer networks, increased number of pumping stations, allocated personnel and expenditures. The use of a lower number of larger WWTP, rather than a higher number of smaller WWTP, was also found advantageous in that regard.

The clustering analysis corroborated the results obtained by the correlation analysis, both in terms of absolute and normalized data. In both cases, it was possible to ascertain a certain aggregation of the SP size dependent factors with the input and output indicators (except for energy production in DW), and of certifications presence with the SP governance model and plants typology. The range of the SP operating conditions related to the DW sector, in absolute values, was better synthesized (through the use of principal components), by the input indicators, certification policy and SP size related factors. And, although the importance of certification policy and SP size related factors remains unquestionable, output indicators and SP independent factors also gain relevance regarding the normalized data. Addressing the WW sector, and the use of absolute values, the output indicators stood out, followed by the input indicators, certification policy and SP size dependent factors. Moreover, the use of normalized data did not alter the relative importance of these factors, although the certification policies assumed a greater relevance.

Summing up, the performed study allowed to draw the following conclusions: i) the number of supplied households and served population are drivers for determining input needs (and outputs production); ii) the SP typology is paramount in the project of mains (DW) and even sewers (WW) grids; iii) the sewers length is paramount for personnel allocation in the WW sector; and iv) SP size and energy certification are paramount for establishing energy production goals.

Furthermore, the main policy implications arising from the current study are the following.

i) Prevention and control of water losses (DW) should be a priority, as these were found to be the main drivers for revenue water in the Portuguese water industry. It should be kept in mind that, apart from water lost by mains leakages, water effectively supplied to households but not paid for may also contribute decisively to non-revenue water in other realities. Furthermore, in the Portuguese case, DW losses were found to present the highest variable importance in the overall PC analysis (including all surveyed indicators);
ii) Concerning total expenditures, personnel allocation should be carefully controlled, even more so than energy costs, in Portugal. Different realities require tailored solutions, which may involve a tighter control on total expenditures including personnel, energy and other operational expenses. Therefore, it is crucial to differentiate, case by case, the operational expense that stands out the most and configures a policy recommendation in that regard. In the Portuguese reality, and given the performed analysis, total expenditures were found to be most influenced by personnel allocation than other (including energy) costs;
iii) Small-scale operators would benefit from aggregation, and large WWTP should be preferably employed, for inputs minimization and even outputs maximization. The results suggest the aggregation of small size Portuguese service providers in order to benefit from economies of scale, whenever possible. Such is also the case regarding the number of treatment plants for overall performance gains;
iv) SP should invest on certification policies (particularly energy certification) which positively influence the operational performance. The ability of a service provider to pursue a certification policy represents both a strong commitment and a decisive driving force to implement such practices in the field, impacting the operational performance. It should be kept in mind that, in order to obtain, and maintain, an energy, environmental, quality or OHS certification, the service provider must, indeed, comply with the demanding requisites on the matter.

Future research is still needed to fully unveil the underlying dependencies found between the governance model (incrementally from direct governance, public owned delegation and concession), SP typology (incrementally from predominantly rural, moderately urban and predominantly urban) and certification policy (mainly for environmental and OHS certifications), possibly driven by the SP size.

The conclusions of this study are aligned with the Portuguese Strategic Plan for Water Supply, Wastewater and Stormwater Management – PENSAARP 2030 (Portuguese Secretary of State for the Environment, 2022)' guidelines, regarding the aggregation of smaller SP to form larger entities. Furthermore, part of the efficiency measures laid out in PENSAARP 2030 require the reduction of water losses and allocated personnel, and increased expenditures control and quality certification practices.

The presented methodology has the potential to be employed with data from other countries to reveal role model SP and corresponding operational indicator drivers, in order to provide or justify policy recommendations.

CRediT authorship contribution statement

António L. Amaral: Conceptualization, Methodology, Investigation, Writing – original draft, Writing – review & editing. **Rita Martins:** Conceptualization, Writing – review & editing, Supervision. **Luís C. Dias:** Conceptualization, Writing – review & editing, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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