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Performance Evaluation of Water Services in Italy: A Meta-Frontier Approach Accounting for Regional Heterogeneities

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Abstract: Data relative to the water services industry in Italy indicate that there is a serious infrastructure gap between the southern regions and isles and the rest of the country. In these geographical areas, water utilities are provided with substantial public grants from the central and local governments to support investments necessary to mitigate the infrastructure divide by increasing capacity and improve service quality. This paper implements a meta-frontier non-parametric approach based on a data envelopment analysis (DEA) to evaluate the efficiencies of 71 Italian water utilities, accounting for the differentiated contexts in which they operate. A short-term perspective was assumed to estimate efficiency, considering the production factors associated with the infrastructure assets as non-discretionary inputs in the specification of the meta-frontier model. The results showed that water utilities operating in the southern regions and isles suffer from an efficiency gap in comparison to those in the northern and central regions. The average efficiency gap was 9.7%, achieving 24.9% in the worst case. Moreover, a more in-depth analysis focusing on the water utilities in the southern regions and isles indicated that scale inefficiencies might be an important determinant of such an efficiency gap. Indeed, slightly more than 69% of the water utilities operated at increasing returns to scale. Evidence from this study raises concern about the appropriate structure of the Italian water service industry and, particularly, the optimal size of the utilities and the financial sustainability of water services in the southern regions and isles.

Keywords: water service industry; Italy; data envelopment analysis; meta-frontier analysis; efficiency; heterogeneity; short-term; non-discretionary inputs

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1. Introduction

Water utilities usually carry out the abstraction, treatment, transport, and distribution of drinking water to users who live in towns and cities. In many countries, they also provide sewerage and wastewater treatment to exploit complementarities and scope economies, although they must comply with the principle of effective unbundling among services [1]. Water service activities often show increasing returns to scale, at least up to a certain size [2–4]. Moreover, unlike in other industries, the economic activities performed in the water services industry are very capital-intensive [5]. Water infrastructure assets call for a high initial investment that has an extremely long pay-back time. Infrastructure assets utilized to provide water services have a high degree of specificity because they cannot be used in any other industry or displaced to different locations. Moreover, the cost function of water utilities is sub-additive. This means that it is cheaper to provide water services meeting the same demand level when only one operator is providing them, whereas providing the same level of services is more expensive when a further utility joins the market. For all the above reasons, the provision of water services is generally considered a natural monopoly industry, in which the long-term marginal costs are below the long-term average costs [6,7]. As a consequence of this, if the tariff paid by users for water services is only a fraction of the marginal cost, the provision of service is not financially viable to the water utility, as this latter is unable to ensure that the costs of service are fully recovered [7]. Hence, a significant subsidization of water services is needed to expand the infrastructure network, promote better water quality, and ensure service reliability [8]. Even when the full-cost principle is adopted, charging users for the real cost of water services and including the expected amount of investment necessary to renovate, replace, or modernize the existing infrastructure, subsidies provided either to service providers as investment grants or to individual users may be necessary to keep the price of water services at an affordable level [9]. Indeed, water utilities tend to exhibit structural deficits as a consequence of misalignment between the tariff, the cost incurred by the utility, and the need to apply the full-cost principle [10]. Particularly, subsidies provided to water operators allow them to reduce their operational cost, i.e., by covering a portion of their operational expenditures, granting tax exemption, allowing the purchasing of production units at lower prices, or to increase long-term investment in infrastructure through direct funding of capital assets. Subsidies also decrease the risk in water utilities induced by the high capital intensity and long pay-back period. Such subsidies translate into lower tariffs for users. Grants are also provided to owners or operators of the infrastructure to improve the quality of the drinking water and, more generally, of water services. In fact, the quality of drinking water and the performance of water services are determined largely by the state of the infrastructure assets.

Italy has a very complex water infrastructure with an aqueduct network length of more than 425,000 km [11]. This complex infrastructure is characterized by several critical issues, which vary from region to region and depend on different factors, such as the age of the pipelines, the low level of technological innovation, and managerial inefficiency. Water losses significantly impact the operational performance of the utilities and environmental sustainability. In 2018 and 2019, the total water losses incurred across the entire network were about 40% on average, with a substantial difference between the north and south regions (i.e., 32% vs. 50%) [11]. The high value of water losses was largely due to the age of the infrastructure. About 60% of the total drinking water network was installed more than 30 years ago, whereas 25% of it was built more than 50 years ago. According to data reported by a recent technical report issued by the Italian Water-Regulating Agency (ARERA), in the year 2016 the replacement rate of the water adduction and distribution network was about 0.39% [12]. Such a value is far below the desirable rate of 2%, estimated assuming a 50-year technical life of the infrastructure. The urban wastewater collection and wastewater treatment also suffered from the sewerage and depuration infrastructure deficit, as they did not adequately comply with EU law and covered only 93% and 90% of households, respectively [13]. According to the Ministry of Ecological Transition, 73% of the infringement procedures by the European Commission against Italy in the water services industry were concentrated in the southern regions of the country [14,15].

Since 2012 after the establishment of the regulatory authority, water services operators have steadily increased their propensity for investment, achieving a per capita expenditure amount of approximately €49 in the year 2019, although annual investment is still far below the European average of €100 per capita [11]. Data relative to the water infrastructure indicate that there is a clear gap between the southern regions of Italy and the rest of the country with respect to asset maintenance and replacement and, finally, to the infrastructure capacity. Such gap relates to the propensity for investment of water service operators, too. From 2012 to 2017, the average investment spending of water operators in the southern regions and isles was about 26 €/inhab., whereas it was 33 €/inhab. and 46 €/inhab. in the northern and central regions, respectively [15,16]. While tariff revenues were able to cover the largest part of investment needs—74.4% and 78.9%, respectively—in the northern and central regions, they covered only 35.3% of investment in southern regions and isles [16]. Hence, to support investment and mitigate the water service infrastructure divide in the south of Italy, both the central and regional governments must provide water service operators with substantial public grants. The weight of public contribution is, thus, an additional element that differentiates the southern regions from the rest of Italy, achieving

64.7% of the total investment funds compared to 25.6% and 21.1% in the northern and central regions, respectively [16].

During the past few decades, the water services industry has experienced considerable changes in many countries to improve the operational efficiency, financial sustainability, and quality of service. However, differently from other industries, there is no universal paradigm that encompasses the market restructuring and liberalization in the water service industry, and several industry configurations have emerged across countries. Therefore, scholars have conducted a plurality of empirical studies with the aim to investigate the impact of restructuring and liberalization reforms on national water and sewerage industry performances, as well as to support policy makers in the search for more efficient configurations [17–19]. Water utilities provide their services under different operational conditions. Consequently, it is likely that they face very differentiated environmental contexts [20]. If such heterogeneity among water operators is neglected, their efficiency evaluation may be greatly biased because specific context conditions may have either an unfavorable or favorable effect on their production function, affecting costs [21,22].

Many scholars have conducted empirical studies employing non-parametric techniques based on data envelopment analysis (DEA) methods to estimate the efficiency of water service operators in Italy [10,23–26]. Some studies have focused on the full range of water services (drinking water, sewerage, and wastewater treatment) [10,25,27], while other studies have concentrated on the individual water services [28,29], and still others considered at the same time both water utility global efficiency and the partial efficiencies of individual water services [30]. Scholars have also investigated exogeneous factors affecting the efficiency of water utilities in Italy. These factors include the regulatory and institutional framework, utility ownership, geographical location and size, and market scope. Particularly, D'Inverno et al. [31] employed a robust and conditional directional distance function composite indicator to measure the efficiency of 93 water utilities for the year 2013, adjusting the efficiency estimate to account for the effects of size, geographical location, degree of diversification, and ownership. Guerrini et al. [29] adopted a conditional order-m efficiency method to evaluate the effect of a set of performance drivers on the efficiency of 137 wastewater plants operating in Tuscany in the year 2014. Five groups of drivers were considered, i.e., plant technology, output quality, sludge disposal technique, wastewater, and plant features. lo Storto [32] performed a two-stage procedure employing a bootstrapped DEA and Tobit regression to measure the effects that some context factors had on 53 water service operators. The context factors included the geographical location and ownership of water operators. Romano et al. [26] used a meta-frontier DEA to measure the efficiency of water utilities in the Veneto and Tuscany regions, also taking into account the heterogeneity due to utility ownership.

Empirical studies aimed at identifying determinants of efficiency differentials in the Italian water services industry have produced ambiguous results. Generally, research has considered ownership, size, and scale economies as potential major determinants of efficiency differentials [25,26,32,33]. A few scholars have evaluated the influence that the geographical location of water utilities has on their efficiency level, employing either non-parametric testing between groups or a two-stage DEA procedure [25,32]. However, both approaches implicitly assume that all the water utilities under examination are homogeneous and adopt the same production function to supply water services. Such an assumption may be unrealistic. In order to better account for regional heterogeneities due to the features of different contexts in which water utilities operate, this study applies a DEA meta-frontier approach, measuring the efficiency of 71 Italian water service operators and employing data relative to the year 2017. Particularly, it is assumed that water utilities in the southern regions and isles of Italy operate under distinct technologies because of the different structure of investment funding (with a greater weight from public grants) and the state of the infrastructure system, which is less developed than in the rest of the country.

The rest of the paper is organized as follows. Section 2 illustrates the DEA meta-frontier method implemented to estimate the efficiencies of the water utilities. In this section, information about model specification, variables, and sample is provided, too. The results are presented and discussed in Section 3. Section 4 concludes by summarizing the research findings, major limitations, and future streams of research.

2. Materials and Methods

2.1. Methods

For some time, data envelopment analysis has been employed to evaluate and compare the efficiency of units that perform the same production process, converting a set of inputs into another set of outputs. For benchmarking purposes, DEA has many strengths compared with parametric methods [34]. In particular, it can handle multiple input and multiple output variables, and it does not require any specification of the functional form of the relationships between inputs and outputs or knowledge of any a priori weighting scheme for the inputs or outputs. Additionally, DEA calculations focus on individual observations and provide information relative to the single units under evaluation rather than to population averages. However, DEA also has a few weaknesses that scholars should consider when they use it to perform efficiency analyses. As it is a non-parametric technique, noise is not explicitly considered in the estimation of efficiency, and estimates are not based on any statistical distribution chosen a priori. DEA is an extreme point technique, and consequently, any measurement error relative to variables may be a cause of critical problems. Finally, DEA provides relative efficiency estimates rather than absolute measurements.

The conventional DEA method assumes that the units under evaluation adopt the same technology to transform inputs into outputs. Put it another way, these units should be homogeneous. To overcome this weakness of the DEA method, scholars have proposed a meta-frontier approach [35–38]. This approach has been widely adopted to compare the performances of non-homogeneous entities that use different production technologies across several industries, e.g., airport operators [39]; franchising services [40]; water services [26,41–46]; tourist hotels [47–49]; banking [50,51]; energy [52]; and health [53,54]. If we assume that a sample of water utilities can be clustered into K ($i = 1, 2, \ldots, k, \ldots K$) groups, a group-frontier can be identified for every group applying DEA. Thus, K group-frontiers can be constructed. The meta-frontier represents the hull that envelops the K group-frontiers that are the boundaries of the same number of production functions [55]. From an input-orientation perspective, it represents the minimum input that can be used producing a given quantity of output by employing the best technology.

The meta-frontier is developed by performing a DEA evaluation of the whole sample. Therefore, water utility efficiency is measured in relation to a common meta-frontier and can be decomposed in two efficiency components. The first efficiency is measured by the distance of the input–output combination of the specific water utility from the group-frontier to which it belongs. The second efficiency estimates the gap between the group-frontier and the meta-frontier. As in the envelopment of the K group-frontiers, there may be infeasible input–output combinations in one of the K production technologies, Tiedemann et al. [56] proposed a method based on the “non-concave meta-frontier concept” that builds a meta-frontier envelopment considering only the input–output combinations that belong to the production technology of at least one of the production technology sets associated with the K groups. To estimate the non-concave meta-frontier efficiency, a two-step procedure is implemented. In the first step, the technical efficiency of a DMU is evaluated relative to its group technology. In the second step, the technical efficiency of a DMU is evaluated relative to the other group technologies. If one of the other group technologies allows the DMU to use a lower input quantity for a given amount of output, the other group technology represents the meta-frontier for this DMU.

Let us further assume that there are N decision-making units (DMUs) that utilize an input vector $x \in \Re^m_+$ to obtain an output vector $y \in \Re^p_+$. The sample size of the k the group is N^k and is subject to $\sum_{k=1}^{K} N^k = N$. The group technology T^k is defined by the set of all feasible input–output combinations for a DMU belonging to group k:

$$T^k = \left\{(x,y) \in \Re_+^{m+p}; x \text{ can produce } y \text{ in group } k\right\} \quad (1)$$

If an output vector y can be produced utilizing an input vector x in one group k, the meta-technology T is defined by all feasible (x,y) combinations as [43]:

$$T = \left\{(x,y) \in \Re_+^{m+p}; x \text{ can produce } y \text{ in some technology set } T^k (k = 1, 2, \ldots, k, \ldots K)\right\} \quad (2)$$

where

$$T = T^1 \cup T^2 \cup \ldots \cup T^k \cup \ldots \cup T^K.$$

Under the assumption of variable returns to scale (VRS) and input orientation [27,30,32], the following linear program can be solved to measure the technical efficiency TE^k and TE of DMU_o with respect to group k and the meta-frontier, respectively:

$$\begin{aligned}
&Min\ \theta^k \\
&\text{s.t.} \\
&\quad \sum_{n=1}^{N^k} \lambda_n^k x_{in} \leq \theta^k x_{io} \quad i = 1, \ldots, m \\
&\quad \sum_{n=1}^{N^k} \lambda_n^k y_{rn} \geq y_{ro} \quad r = 1, \ldots, p \\
&\quad \sum_{n=1}^{N^k} \lambda_n^k = 1 \\
&\quad \lambda_n^k \geq 0 \quad n = 1, \ldots, N^k
\end{aligned} \quad (3)$$

where x_{in} and y_{rn} are the respective amounts of the inputs $i = 1, \ldots, m$ and outputs $r = 1; \ldots, p$, θ^k is the technical efficiency measure of DMU_o; and λ_n^k is an intensity scalar.

For DMU_o, the proximity of the production frontier relative to group k to the meta-frontier is measured by the technology gap ratio [38]:

$$TGR^k = \frac{TE}{TE^k} \leq 1$$

2.2. Sample and Data

The sample considered in the empirical study was made of 71 Italian water utilities, including public, private, and public-private-owned companies. All utilities except four provided the full range of services, i.e., drinking water supply and distribution, sewerage, and wastewater treatment in line with the legislation in the area. A single utility provided the drinking water service to one of the largest Italian cities and some minor towns, while the sewerage service and wastewater treatment services were provided by the municipalities and the regional government. However, this utility had the responsibility for bill issuing and payment collection for the sewerage and wastewater treatment services, as well as the drinking water service. Data relative to the fiscal year of 2017 were retrieved from public sources, such as water utility websites, technical literature, and the databank of the financial statements of the Italian Chambers of Commerce. Figure 1 shows the structure of the sample. The whole sample was split into two groups: one including the largest number of water utilities, which provided water services to customers in the northern and central regions of Italy (48 in total), and the other containing the twenty-three utilities that operated in the southern regions and isles (Abruzzo, Apulia, Basilicata, Calabria, Campania, Molise, Sardinia, and Sicily). Hence, these two groups were associated with the same number of geographical macro-regions. For simplification purposes, the first one was denominated the NCR group, and the second one was denominated the SRI group. Figure 2 shows a map of Italy reporting the geographical macro-regions. In this study, the northern and central regions were aggregated in one single group having similar characteristics. Table 1 reports further details about the pooled sample and the two groups, presenting major statistics relative to size and ownership. On average, the water utilities in the SRI group had a larger size in terms of number of connections but were smaller with respect to the number of municipalities provided with water services. Both groups contained a greater number of water utilities classified as "public" firms, reflecting the structure of the pooled sample.

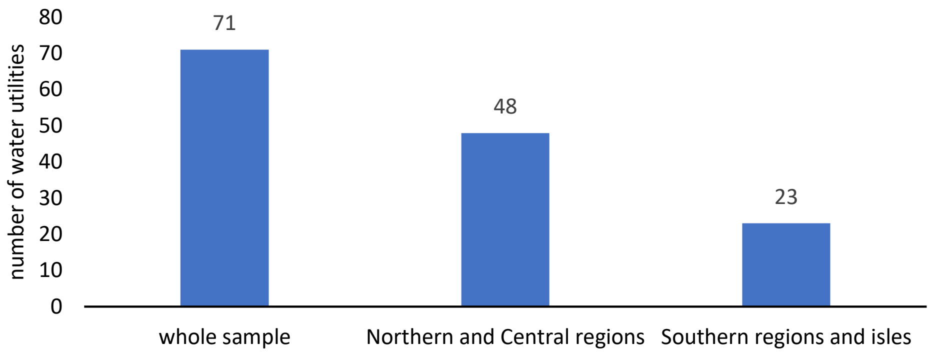

Figure 1. Structure of the water utilities sample.

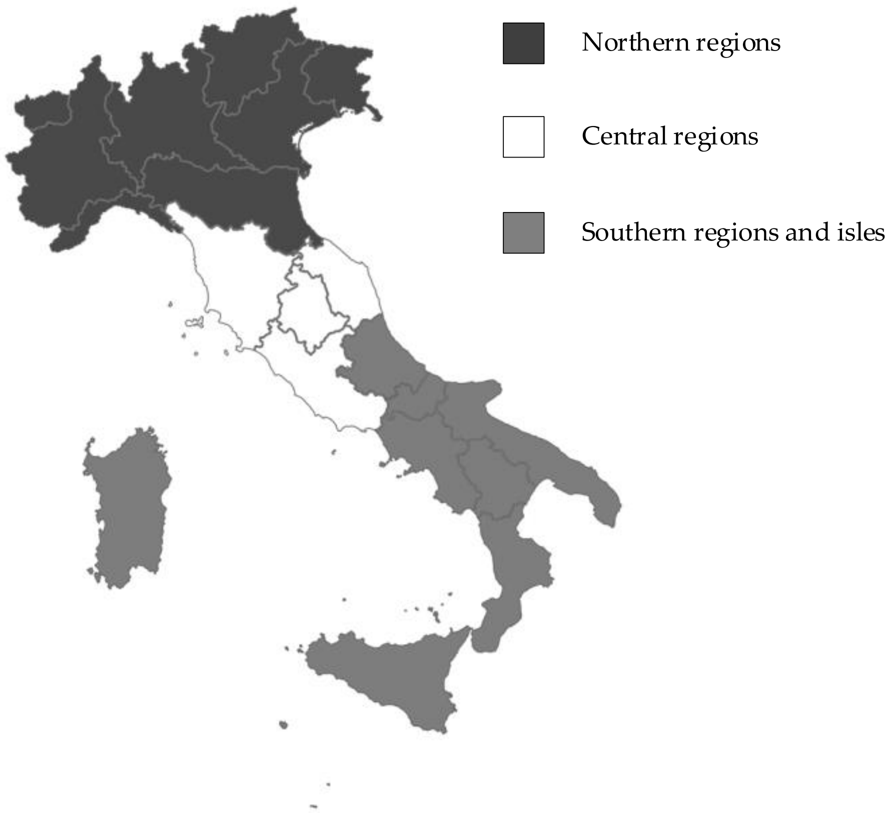

Figure 2. Map of geographical macro-regions in Italy.

Table 1. Size and ownership of the pooled sample and groups.

Variable		Main Statistics			
		Mean	*St.dev.*	*Max*	*Min*
number of connections	WS	177,792	172,344	999,589	5067
	SRI	208,607	238,496	999,589	8469
	NCR	163,027	130,098	574,415	5067
number of municipalities	WS	66	67	345	1
	SRI	64	83	345	1
	NCR	67	59	293	1
		Number of water utilities			
		Public		*Mixed private-public/ fully private*	
type of ownership	WS	45		26	
	SRI	14		9	
	NCR	31		17	

Note: WS = whole sample; SRI = southern regions and isles group; NCR = northern and central regions group.

2.3. Model Specification and Variables

The variables used for model specification comprised 5 inputs and 1 output. As common in studies like this, the selection of these variables was guided by previous research, as well as by the availability of data. A list of variables used as inputs and outputs in the specification of the water utilities production function can be found in [17,57,58]. In this study, both physical and financial variables were adopted. Particularly, inputs included the yearly total production cost (I1) incurred by a single utility to supply water services to customers [18,30,59]; three physical variables measuring the infrastructure capacity, i.e., the aqueduct pipeline length (I2) [18,22,30,59–64], the sewerage pipeline length (I3) [18,30,65], and the number of wastewater treatment facilities (I4) [10,30]; and a further physical variable measuring the water losses (I5) [66–68]. The only output used in the efficiency analysis was the total production value (O1). This variable measured the overall economic value generated by a water utility in the fiscal year, including the economic value of equipment and capital goods it built using its own resources in addition to revenues. Thus, it provided a better and more complete evaluation of the total economic value produced by a water utility [10]. Table 2 presents variable statistics for the whole sample and the two groups. Consistent with the nature of water services, an input orientation was assumed to estimate the efficiency of the water utilities. Indeed, water utilities must meet the demand for water services by minimizing the usage of resources [21,69]. Moreover, because the efficiency analysis was performed by adopting a short-term perspective, inputs related to the infrastructure capacity were included in the analysis as "non-discretionary" inputs [70], while water losses were considered as a "semi-discretionary" input of the water service production function [71]. According to figures provided by the Territorial Cohesion Agency of the Italian Government, the average time necessary to complete a public works project in the water service industry is about 5,2 years [72]. Hence, in the short-term, the efficiency improvement of water services depends, for the most part, on reduction in the production cost and, partially, on reduction in water losses. Indeed, improving or redesigning the infrastructure capacity is not under the control of the water utility managers in the short-term, but rather it is the outcome (and goal) of a long-range planning process. An effective reduction in water loss rates to an acceptable level depends on several factors. These include mains pressure, local climate and topography, local value of water, age of the system, types of mains and soil, maintenance and repair operations management, inaccuracy in metering, an unauthorized consumption. To a certain extent, some of these factors are under the control of a water utility, even in the short-term. In this study, the water loss variable was measured by the percentage of water that was lost along the supply and distribution pipelines. As water loss gives rise to revenue decrease for the water utility, environmental impact, and social detriment when demand is unmet, this variable was associated with an opportunity cost that should be reduced, and consequently, it was included in the input set.

Table 2. Input and output variables.

Variable	Type	Measurement	Group	*Mean*	*St.dev.*	*Max*	*Min*
total production cost (I1)	input	€	WS	68,133,268	91,116,496	503,180,963	2,093,835
			SRI	76,648,022	112,999,807	503,180,963	2,093,835
			NCR	64,053,282	79,596,258	442,589,659	4,675,526
aqueduct pipeline length (I2)	input	km	WS	3694	3889	25,000	86
			SRI	3886	5566	25,000	86
			NCR	3602	2829	12,428	99
sewerage pipeline length (I3)	input	km	WS	2014	2463	16,000	0
			SRI	1890	3411	16,000	0
			NCR	2073	1893	9439	38
number of wastewater treatment facilities (I4)	input	unit	WS	87	107	500	0
			SRI	55	83	337	0
			NCR	103	114	500	1
water losses (I5)	input	percentage	WS	40.91	11.63	77.30	19.83
			SRI	48.17	8.48	68.51	33.82
			NCR	37.44	11.39	77.30	19.83
total production value (O1)	output	€	WS	77,520,472	108,808,044	613,872,000	2,326,190
			SRI	80,412,017	118,055,515	522,787,134	2,326,190
			NCR	76,134,940	105,370,934	613,872,000	5,297,696

Note: WS = whole sample; SRI = southern regions and isles group; NCR = northern and central regions group.

The selection of input and output variables is an important step of model specification in DEA because the results of the efficiency analysis are conditioned by these choices [73]. Such choices are critical if the sample size is particularly small in comparison to the number of DMUs and when the DEA model is performed under the assumption of variable returns to scale [74]. In this case, to improve the power of the DEA model to better discriminate between efficient and inefficient DMUs, its dimensionality could be reduced by substituting the original set of variables, or some of them, by introducing an aggregate measure. To this aim, some scholars have proposed the adoption of a principal component analysis (PCA) to reduce the number of variables used in DEA model specification [75,76]. PCA allows the avoidance of efficiency over-estimation bias in a small size sample due to the relatively large number of variables compared to the number of DMUs without introducing any subjectivity in the efficiency analysis, as the weights utilized to aggregate variables are objectively determined [75]. Scholars also demonstrated that the use of a PCA worked better than other methods [74]. Therefore, because the SRI group contained only 23 units, a PCA was applied in this study, too. In advance, a correlation analysis was performed to identify variables that would be potential candidates for reduction. Table 3 shows the Pearson correlation values between the variables. The figures indicate that inputs I1, I2, and I3 were highly correlated. However, consistent with the different assumptions made with respect to inputs (i.e., discretionary vs. non-discretionary and semi-discretionary types), a PCA was performed considering only inputs I2, I3, I4, and I5 and excluding I1. Table 4 presents the results obtained from performing the PCA. The measurements of variables were preliminarily divided by their means to standardize original variables. As expected, only I2 and I3 emerged as being good candidates for reduction. The new variable was obtained by aggregating I2 and I3 using loadings as weights. This variable provided a measurement of the water utility infrastructure network and was named I23 and identified as “network length”.

Table 3. Pearson correlations.

	I1	**I2**	**I3**	**I4**	**I5**	**O1**
I1	1 (0.000)					
I2	0.864 (0.000)	1 (0.000)				
I3	0.880 (0.000)	0.934 (0.000)	1 (0.000)			
I4	0.414 (0.005)	0.550 (0.000)	0.503 (0.000)	1 (0.000)		
I5	0.119 (1.000)	0.094 (1.000)	−0.011 (1.000)	0.005 (1.000)	1 (0.000)	
O1	0.989 (0.000)	0.822 (0.000)	0.842 (0.000)	0.414 (0.005)	0.115 (1.000)	1 (0.000)

Note: Bonferroni probabilities are indicated in parentheses.

Table 4. Inputs after data reduction.

Original Variable		**New Variable**				
Name	***Type***	***Component Loading***	***% Variance***	***Type***	***Name***	***Description***
I2 I3	input input	0.968 0.979	51.63	input	I23	network length
I4	input	0.911	21.76	input	I4	number of wastewater treatment facilities
I5	input	1.000	25.13	input	I5	water losses

Note: variables I4 and I5 remained unchanged after the implementation of the reduction procedure.

Moreover, the model specification was developed assuming variable returns to scale (VRS). This assumption is consistent with the findings that have emerged from previous empirical research focusing on the water services in Italy [2,26,30,32]. Because some variables had zero values, the data were preliminarily prepared before implementing the DEA model, as suggested by the literature [77].

3. Results and Discussion

The meta-frontier efficiency analysis was based on the assumption that the different K groups did not share the same production technology. Hence, before estimating the water utility meta-frontier efficiencies, statistical testing was performed to determine whether there were any statistically significant differences between the two macro-regions considered in the study [42]. Particularly, it was assumed that, if water utilities operate in two macro-regions that differ with respect to the water network infrastructure development and quality, public fund availability, administrative efficiency, and effectiveness, the water utilities managers must employ different quantities of inputs or different combinations of them to provide service with the same or different output amounts. That necessarily implies the utilization of different production technologies. Thus, statistical testing was conducted considering both individual input and output variables, and specific combinations of them were evaluated in terms of their ratios. Because the inputs, outputs, and their ratios showed non-normal distributions, a two-tailed Mann–Whitney U test was applied. The results of the statistical testing are shown in Table 5. For most variables and combinations, the hypothesis that the water utilities employed two different technologies was statistically acceptable, and estimating the meta-frontier efficiencies was meaningful.

Table 5. Mann–Whitney U test statistics for differences in the two groups.

Variable	Sum of Ranks		Mann–Whitney U Value	Z Score	*p*-Value
	NCR	*SRI*			
total production cost (I1)	1744	812	536	0.19045	0.84930
aqueduct pipeline length (I2)	1715	741	465	1.06281	0.28914
sewerage pipeline length (I3) *	1870	686	410	1.73859	0.08186
number of wastewater treatment facilities (I4) *	1941	615	339	2.61095	0.00906
water losses (I5) ***	1396	1160	220	−4.07308	0.00001
total production value (O1)	1763	793	517	0.4239	0.67448
I1/I2	1608	948	432	−1.46828	0.14156
I1/I3 *	1508	770	332	−1.71793	0.08544
I1/I4 **	1454	824	278	−2.46909	0.01352
O1/I1 ***	2102	454	178	4.58913	0.00001
O1/I2	1642	914	466	−1.05052	0.29372
O1/I3	1568	710	392	−0.88331	0.37886
O1/I4 **	1474	804	298	−2.19088	0.02852

Note: * indicates the result is significant at $p < 0.10$; ** indicates the result is significant at $p < 0.05$; *** indicates he result is significant at $p < 0.01$.

3.1. Efficiency Scores

Figures 3 and 4 show the measurements and characteristics of the water utility efficiencies calculated with respect to the individual groups and the meta-frontier. Detailed scores are reported in Table A1 in the Appendix A.

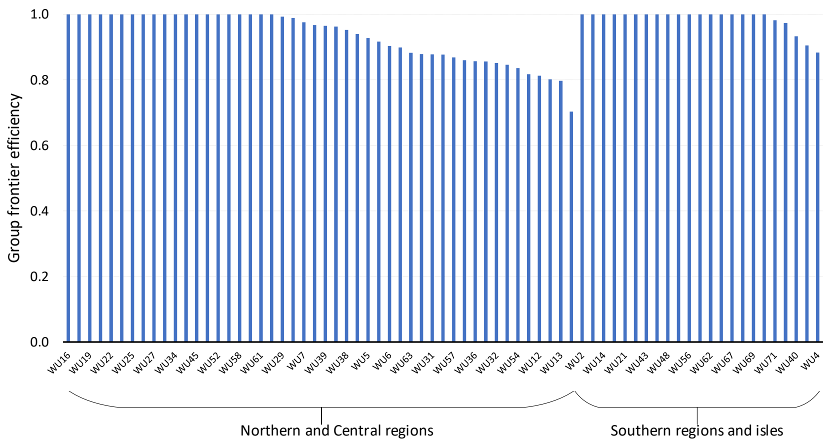

Figure 3. Group frontier efficiency scores.

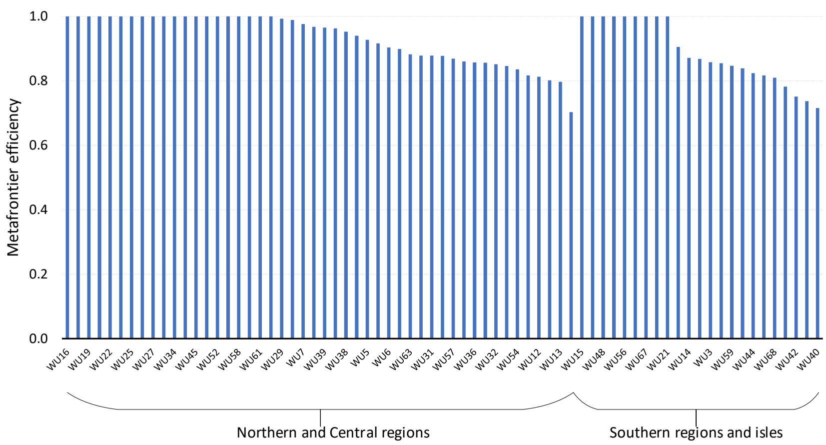

Figure 4. Meta-frontier efficiency scores.

The efficiency analysis performed at the group level showed that water utilities belonging to the SRI group were more homogeneous than water utilities in the NCR group, having a lower standard deviation of the efficiency score (equal to 0.033) (Figure 3 and Table 6). Furthermore, the SRI group also contained water utilities achieving, on average, a higher efficiency score, i.e., 0.986 vs. 0.934. In this group, there was a greater number of 100%-efficient water utilities (78.26%), as clearly shown in the right side of Figure 3. The minimum efficiency scores in the SRI and NCR groups were 0.883 and 0.703, respectively. This means that the worst water utility in the SRI group might potentially have saved its current production cost by about 12%, while the worst utility in the NCR group had more room for improvement at nearly 30%. The results from this analysis suggest that, as a group, the SRI water utilities outperformed the NCR ones.

Table 6. Main statistics relative to efficiency measured with respect to the meta-frontier and group frontiers.

	Efficiency Measure								**TGR**		
	With Respect to the Meta-Frontier				***With Respect to the Group Frontier***						
	Mean	***St.dev.***	***Min***	***100% Efficient***	***Mean***	***St.dev.***	***Min***	***100% Efficient***	***Mean***	***St.dev.***	***Min***
WS	0.920	0.087	0.703	40.85	0.951	0.070	0.703	53.52	0.968	0.069	0.751
SRI	0.890	0.100	0.715	39.13	0.986	0.033	0.883	78.26	0.903	0.033	0.751
NCR	0.934	0.077	0.703	41.67	0.934	0.077	0.703	41.67	1.000	0.000	1.000

Note: WS = whole sample; SRI = southern regions and isles group; NCR = northern and central regions group.

Due to the heterogeneity between the water utilities belonging to the two macro-regions, the efficiencies that were estimated under different group frontiers could not be directly compared. Therefore, the efficiency of the water utilities was estimated under a meta-frontier, too. The results of this further efficiency analysis are presented in Figure 4 and Table 6. As expected, efficiencies estimated with respect to the meta-frontier were generally lower than the efficiencies measured with respect to the group frontier. Under the meta-frontier analysis, the average efficiency of the water utilities of the NCR group remained unchanged, whereas it decreased by about 9.7%, achieving the value of 0.890, for the utilities in the SRI group. The minimum efficiency score estimated in this latter group decreased even sharper by 19%. The rate of 100%-efficient water utilities in the SRI group dropped to 39.13% from 78.26%. The average TGR measurement was 1.000 with no variance for the NCR group and 0.903 for the SRI group. The Mann–Whitney U test statistics provided statistical support for this difference in TGR values (Table 7). The TGR provided a measurement of the distance between the group frontier and the meta-frontier. When the TGR is equal to unity, the group-frontier and the meta-frontier match. These data show that the water utilities that were in the SRI group lagged behind those in the NCR group relative to the efficient utilization of their production resources, and the meta-frontier that enveloped the group-frontier was substantially constructed by the water utilities of the NCR group. These findings are consistent with previous research [32]. By using a bar chart format, Figure A1 in the Appendix A displays the relative efficiency increase for the utilities in the southern regions and isles passing from the meta-frontier to the group analysis. In the next section, the results of a more in-depth analysis focusing on the SRI group are presented.

Table 7. Mann–Whitney U test statistics for differences in the meta-frontier and group efficiencies.

Efficiency	Sum of Ranks		Mann–Whitney U Value	Z Score	*p*-Value
	NCR	*SRI*			
Meta-frontier efficiency (VRS)	1849.5	706.5	430.5	1.48671	0.13622
Group frontier efficiency (VRS) ***	1491	1065	315	−2.90584	0.00362
TGR ***	2040	516	240	3.82735	0.00012

Note: (VRS) and (CRS) indicate that efficiency was calculated under the assumptions of variable returns to scale and constant returns to scale, respectively. SRI = southern regions and isles group; NCR = northern and central regions group. *** indicates the result is significant at $p < 0.01$.

3.2. Determinants of the Efficiency Gap

In order to carry out a more in-depth analysis of the SRI group to identify the factors that mostly determined the efficiency gap from the meta-frontier, this group was further split into two sub-groups on the basis of the TGR measurements. Particularly, the first sub-group included all the water utilities having a TGR value below unity (TGR < 1), while the second sub-group contained the water utilities having a TGR measure equal to one (TGR = 1).

The list of factors taken into consideration in this study and their statistics are reported in Tables 8 and 9. These factors included both the input and output variables employed in the specification of the water utility technology, as well as some further variables measuring the market size, operating conditions, and utility ownership. These latter variables have also been considered in previous studies, either as factors of production technology or as exogeneous or environmental variables influencing water utilities operations. Specifically, the number of connections and the number of municipalities provided with water services were included in the analysis to account for the market size of water services [10,32,78–81]. The number of connections was also used in this study as the bottom number of a ratio to construct two composite indicators, i.e., the average production cost and the average production value. Both indicators provided important insights about the possibility to exploit scale economies and achieve financial sustainability by water operators, measuring their production cost and production value per single connection [82].

Table 8. Main statistics relative to the efficiency measurements and factors affecting water services efficiency in the "TGR < 1" and "TGR = 1" sub-groups.

Variable	TGR < 1				TGR = 1			
	Mean	*St.dev*	*Max*	*Min*	*Mean*	*St.dev*	*Max*	*Min*
Meta-frontier efficiency (VRS)	0.813	0.052	0.871	0.715	0.990	0.030	1.000	0.905
Group frontier efficiency (VRS)	0.982	0.036	1.000	0.883	0.991	0.030	1.000	0.905
Group frontier efficiency (CRS)	0.948	0.051	1.000	0.875	0.986	0.032	1.000	0.905
Scale efficiency ratio	0.965	0.041	1.000	0.890	0.995	0.015	1.000	0.953
Production cost	57,167,585	72,099,541	281,865,384	14,107,130	105,872,589	150,342,701	503,180,963	2,093,835
Production value	57,194,003	75,755,017	292,572,118	14,342,112	110,595,436	156,926,045	522,787,134	2,326,190
Average production cost	393	388	1666	180	322	125	530	141
Average production value	407	394	1693	177	336	123	533	170
Water losses	46.77	9.44	68.51	33.82	49.98	7.12	56.73	34.22
Aqueduct pipeline length	2814	3065	12,000	527	5280	7706	25,000	86
Sewerage pipeline length	1461	1652	6620	397	2448	4918	16,000	0
Number of wastewater facilities	65	90	337	4	41	75	184	0
Number of connections	164,402	177,312	713,986	8469	266,074	301,047	999,589	8677
Number of municipalities	63	87	345	10	65	83	255	1
Connection density (aqueduct)	74	49	170	14	78	36	115	27
Connection density (sewerage)	127	63	267	18	194	146	465	62
Connection density (wastewater)	5457	6252	23,081	1052	34,967	41,726	101,234	1617
Connection density (municipalities)	3229	2098	7018	847	32,670	88,745	285,000	1446

Note: (VRS) and (CRS) indicate that efficiency was calculated under the assumptions of variable returns to scale and constant returns to scale, respectively.

Table 9. Type of returns to scale and ownership.

Group	Ownership	
	Public	*Mixed Private-Public/ Fully Private*
TGR < 1	8	5
TGR = 1	6	4
	Returns to scale	
	Increasing	*Constant*
TGR < 1	9	4
TGR = 1	2	8

Four further indicators were developed to generate various measurements of connection density. All these indicators were in the form of ratios and had the number of connections as the top of the fraction. Three of them measured the connection density with respect to water infrastructure capacity (aqueduct and sewerage networks and wastewater treatment facilities). Hence, they allowed the description of the structural characteristics of the water infrastructure [83]. The last density indicator was measured as the ratio of the number of connections to the number of municipalities provided with water services. These densities could be important cost drivers [33]. However, the effect on cost could be ambiguous. On the one hand, when users are very close together, fewer infrastructure assets are necessary to provide water services. Thus, a greater user concentration may offer not negligible cost savings, such as reduced energy expenditure for water pumping or lower water losses along the supply pipeline. On the other hand, however, costs may increase because of a high rate of urbanization, which requires more complex installation and maintenance. Then, a further index was adopted to evaluate the size of the scale efficiencies. This index was computed as the ratio of the group efficiency estimated under the assumption of constant returns to scale to the group efficiency estimated assuming variable returns to scale [84,85]. Further details about the types of returns to scale are showed in Table 9. The rule suggested by Fare et al. [86] was applied to classify the different types of returns to scale.

Table 8 presents statistics relative to efficiencies for both of the sub-groups. The results of the Mann–Whitney U test performed to compare the two sub-groups are summarized in Table 10. The outcome of the Mann–Whitney U test revealed that there were statistically significant differences between the two sub-groups relative to the following variables: scale efficiency ratio and type of returns to scale, production value, number of wastewater facilities managed by the water utility, and the connection density relative to the wastewater assets capacity. Specifically, water utilities suffering from an efficiency gap (TGR < 1) generated a relatively lower production value in the year 2017, although this was partially due to the smaller firm size. For the water utilities belonging to this sub-group, on average, the production value was substantially equal to the production cost. On the contrary, for water utilities belonging to the other sub-group (TGR = 1), the average production value was slightly higher than the average production cost (€110,595,435 vs. €105,872,589), providing an important margin to ensure financial sustainability. Even though the comparison between the infrastructure network length (aqueduct and sewerage pipeline networks) of the water utilities in the two sub-groups did not highlight any statistically significant difference, their measurements suggested that the smaller size of the infrastructure assets of the water utilities in the first sub-group might be a potential determinant of the efficiency gap for the latter. The average lengths of the aqueduct and sewerage pipeline networks of the water utilities belonging to the first sub-group were 2814 km and 1461 km, respectively. The water utilities of the second sub-group had a more extended infrastructure network, with the average lengths of the aqueduct and sewerage pipeline networks equal to 5280 km and 2448 km, respectively. Maintaining focus on the characteristics of the infrastructure assets, the figures also indicate that the water utilities in the first sub-group had a lower connection density with respect to wastewater facility endowment. For this kind of density, economies are likely to be important in considering the urban infrastructure providing water services. Nevertheless, research findings relative to the impact of density economies on efficiency remain ambiguous [80]. What emerged from this study with respect to the impact of the connection density of wastewater facilities on operator efficiency seems to support the idea that a low connection density may be associated to a lower efficiency measurement. Hence, efficiency grows when connection density increases [87–89]. Neither results relative to the connection density measured with respect to the aqueduct and sewerage infrastructure nor those relative to connection density relative to municipalities were statistically significant. Thus, the argument of a positive relationship between connection density and efficiency could not be fully accepted, and we should not put aside the idea that, in some cases, a high level of connection density may even cause efficiency decrease as a consequence of the increasing complexity of the infrastructure network and management burden [90].

Table 10. Mann–Whitney U test statistics for differences relative to efficiencies and factors affecting water services efficiency in the "TGR < 1" and "TGR = 1" groups.

Variable	Sum of Ranks		Mann–Whitney U Value	Z Score	*p*-Value
	TGR < 1	*TGR = 1*			
Meta-frontier efficiency (VRS) ***	91	185	0	−4.00012	0.00001
Group frontier efficiency (VRS)	143.5	132.5	52.5	−0.74421	0.45931
Group frontier efficiency (CRS) *	124	152	33	−1.95355	0.05118
Scale efficiency ratio **	120	156	29	−2.20162	0.02782
Returns to scale type *	124	152	33	−1.95355	0.05118
Production cost	1367	1048	583	0.01816	0.98404
Production value *	1215	1200	435	−1.80963	0.07032
Average production cost	168.5	131.5	63.5	−0.35132	0.72634
Average production value	166	134	61	−0.49771	0.61708
Water losses	135	141	44	−1.27136	0.20408
Aqueduct pipeline length	417.5	285.5	149.5	0.55183	0.58232
Sewerage pipeline length	366	195	90	1.54812	0.12114
Number of wastewater facilities *	187	89	34	1.89153	0.05876
Number of connections	613	468	258	0.03324	0.97606
Number of municipalities	169.5	106.5	51.5	0.80623	0.41794
Connection density (aqueduct)	150	126	59	−0.34111	0.72786
Connection density (sewerage)	121	69	30	−0.74552	0.45326
Connection density (wastewater) **	106	84	15	−2.06109	0.03942
Connection density (municipalities)	138	138	47	−1.08531	0.27572
Ownership	157	119	64	0.03101	0.97606

Note: (VRS) and (CRS) indicate that efficiency was calculated under the assumptions of variable returns to scale and constant returns to scale, respectively. * indicates the result is significant at $p < 0.10$; ** indicates the result is significant at $p < 0.05$; *** indicates the result is significant at $p < 0.01$.

When a utility provides more than one service (i.e., supply of drinking water and sewerage), the economies of scope need to be considered because of their possible influence on efficiency. Additionally, scope economies may also have scale effects [59]. However, findings from previous empirical research focusing on the Italian water industry do not provide univocal evidence of the positive effect of the joint production of water services on efficiency [59]. Conversely, studies that have focused on other countries have found support for the existence of scope economies [91–93]. Particularly, there is evidence of some interrelation between the costs for providing drinking water service and sewerage service [90]. Therefore, the relationship among the economies of density, economies of scale, and economies of scope should be explored more in-depth on a case-by-case basis because of their complex interaction in order to evaluate their effect on utility efficiency. For instance, the previous literature found that economies of scope may be important only when the size of water utilities is small [94]. The examination of the statistics and the Mann–Whitney U test relative to the scale efficiency ratio and type of returns to scale corroborated the belief that size might be a major determinant of the efficiency gap experienced by the utilities in the first sub-group. The water utilities in this group had a higher average scale inefficiency equal to 3.5% (0.035 = 1 − 0.965), achieving the lowest score of 11% in the worst case. Such an inefficiency was likely linked to the fact that the water utilities operated at far from the optimal size. Indeed, in this sub-group, the water utilities having increasing returns to scale were dominant in comparison to the second sub-group (69.2% vs. 20%). In this latter sub-group, most of the utilities operated at constant returns to scale (80%) (see Table 9). These findings are consistent with what emerged from earlier research, which found proof of the relevance of scale economies in achieving increasing efficiency [95]. Nevertheless, the comparison between the two sub-groups did not provide any statistical evidence that either the market size of the service measured in terms of number of municipalities and the number of connections (Tables 8 and 10) or the ownership affected the efficiency gap (Tables 9 and 10).

4. Conclusions

Measuring the efficiency of the utilities in the water industry has become a key tool to promote and achieve performance improvement by identifying the factors that mostly affect it. The proper measurement of utility efficiency requires taking into account the context variables that may affect the efficiency score. If these variables are not considered, the efficiency estimation procedure may lead to an unrealistic measurement of the water utility performance.

This paper applied a meta-frontier-DEA-based approach to evaluate the efficiency of 71 Italian water utilities. In order to account for the differentiation of the operating contexts, the whole sample was split into two groups: one including the water utilities that provided services in the northern and central regions and the other one including the utilities providing services to customers in the southern regions and isles. Water utilities in the southern regions and isles operated under distinct production technologies because of the different structure of investment funding, with greater availability of public grants supporting investment and an underdeveloped state of infrastructure system, which negatively affected the way service was provided. Additionally, a short-term perspective was assumed in the calculation of efficiency. In this regard, the production factors associated with the infrastructure assets were considered as non-discretionary inputs in the specification of the meta-frontier model.

The results from this study may help to improve the level of understanding of factors affecting the level of efficiency of water operators in Italy and may have important implications for policy programming and management. The findings indicated that water utilities operating in the southern regions and isles actually suffered from an efficiency gap in comparison to the water utilities in the northern and central regions. The average efficiency gap was 9.7%, achieving 24.9% in the worst case. A more in-depth analysis focusing on the water utilities belonging to the southern region and isles group revealed that scale inefficiencies could be an important determinant of the efficiency gap. Indeed, most of these water utilities operated at increasing returns to scale (69.2%). However, the results only partially confirmed that there existed a positive linkage between the connection density and efficiency and the existence of economies of scope. Additional research is necessary to explore this issue.

Further limitations of this study are given by the size of sample and the utilization of data relative to one single year to perform the efficiency analysis. Both limitations were due to the availability of public data. While on the one hand it was easy to collect yearly financial data from public sources for water utilities that were incorporated as enterprises, on the other hand, when the water services were provided by the municipalities themselves, financial data relative to the management of service were not accessible [96]. Similarly, updated figures relative to the infrastructure capacity were often unavailable.

The evidence provided by this study raises concerns about the appropriate market structure for the water service industry in Italy and, particularly, the optimal size of the utilities and the financial sustainability of water services in the southern regions and isles. Funding granted to the water industry in the southern regions and isles did not allow for the closure of the efficiency gap between them and the rest of the country. Greater investment for improving water services infrastructure and technologies is necessary to reduce and monitor water losses to an acceptable rate more effectively. Reducing water losses can help the water utilities to improve their performances and, at the same time, provide benefit to the environment.

A policy effort should also be addressed to support mergers and acquisitions in the industry to take advantage of economies of scale and scope in order to increase efficiency and ensure financial viability. This is especially critical for smaller utilities in the southern regions and isles, which operate in a local market. In addition, increasing the sizes of these water utilities can make it easier for private financial support to be secured.

Furthermore, from a benchmarking perspective, the findings from this study indicated that the efficiencies of water utilities should not be directly compared if they operate in different geographical regions in which the characteristics of the existing infrastructure severely constrain their operational conditions.

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Conflicts of Interest: The author declares no conflict of interest.

Appendix A

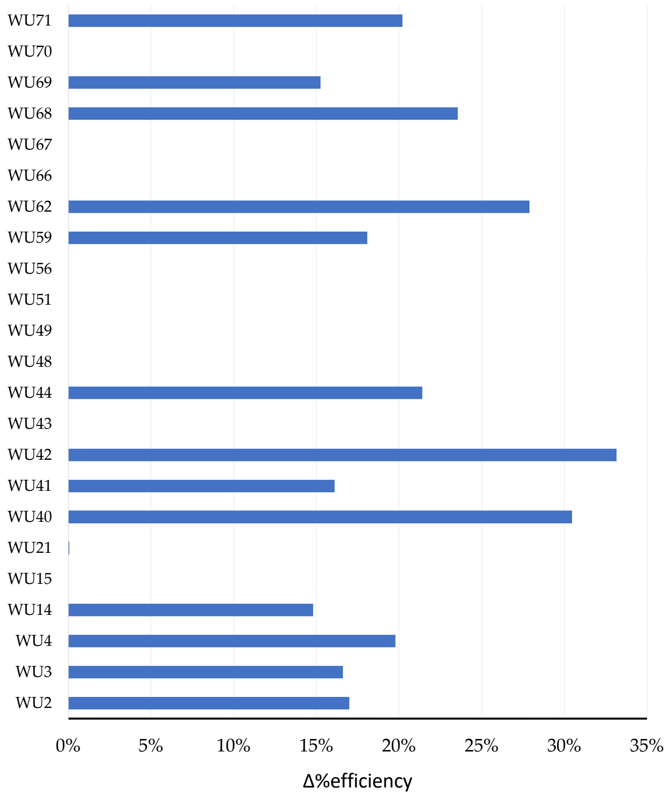

Figure A1. Efficiency variation from meta-frontier to group analysis for the water utilities in the southern regions and isles.

Table A1. Group and meta-frontier efficiency scores.

DMU	Group	Meta-Frontier Efficiency Score	Group Frontier Efficiency Score	TGR	DMU	Group	Meta-Frontier Efficiency Score	Group Frontier Efficiency Score	TGR
WU1	NCR	0.703	0.703	1.000	WU2	SRI	0.855	1.000	0.855
WU5	NCR	0.927	0.927	1.000	WU3	SRI	0.858	1.000	0.858
WU6	NCR	0.903	0.903	1.000	WU4	SRI	0.737	0.883	0.835
WU7	NCR	0.976	0.976	1.000	WU14	SRI	0.871	1.000	0.871
WU8	NCR	0.899	0.899	1.000	WU15	SRI	1.000	1.000	1.000
WU9	NCR	0.860	0.860	1.000	WU21	SRI	1.000	1.000	1.000
WU10	NCR	0.989	0.989	1.000	WU40	SRI	0.715	0.933	0.767
WU11	NCR	0.916	0.916	1.000	WU41	SRI	0.839	0.974	0.861
WU12	NCR	0.813	0.813	1.000	WU42	SRI	0.751	1.000	0.751
WU13	NCR	0.797	0.797	1.000	WU43	SRI	1.000	1.000	1.000
WU16	NCR	1.000	1.000	1.000	WU44	SRI	0.824	1.000	0.824
WU17	NCR	0.846	0.846	1.000	WU48	SRI	1.000	1.000	1.000
WU18	NCR	1.000	1.000	1.000	WU49	SRI	0.905	0.905	1.000
WU19	NCR	1.000	1.000	1.000	WU51	SRI	1.000	1.000	1.000
WU20	NCR	1.000	1.000	1.000	WU56	SRI	1.000	1.000	1.000
WU22	NCR	1.000	1.000	1.000	WU59	SRI	0.847	1.000	0.847
WU23	NCR	0.878	0.878	1.000	WU62	SRI	0.782	1.000	0.782
WU24	NCR	1.000	1.000	1.000	WU66	SRI	1.000	1.000	1.000
WU25	NCR	1.000	1.000	1.000	WU67	SRI	1.000	1.000	1.000
WU26	NCR	1.000	1.000	1.000	WU68	SRI	0.809	1.000	0.809
WU27	NCR	1.000	1.000	1.000	WU69	SRI	0.868	1.000	0.868
WU28	NCR	1.000	1.000	1.000	WU70	SRI	1.000	1.000	1.000
WU29	NCR	0.993	0.993	1.000	WU71	SRI	0.817	0.982	0.832
WU30	NCR	0.940	0.940	1.000					
WU31	NCR	0.878	0.878	1.000					
WU32	NCR	0.852	0.852	1.000					
WU33	NCR	0.802	0.802	1.000					
WU34	NCR	1.000	1.000	1.000					
WU35	NCR	0.877	0.877	1.000					
WU36	NCR	0.857	0.857	1.000					
WU37	NCR	1.000	1.000	1.000					
WU38	NCR	0.952	0.952	1.000					
WU39	NCR	0.965	0.965	1.000					
WU45	NCR	1.000	1.000	1.000					
WU46	NCR	0.817	0.817	1.000					
WU47	NCR	0.962	0.962	1.000					
WU50	NCR	1.000	1.000	1.000					
WU52	NCR	1.000	1.000	1.000					
WU53	NCR	0.856	0.856	1.000					
WU54	NCR	0.836	0.836	1.000					
WU55	NCR	1.000	1.000	1.000					
WU57	NCR	0.869	0.869	1.000					
WU58	NCR	1.000	1.000	1.000					
WU60	NCR	1.000	1.000	1.000					
WU61	NCR	1.000	1.000	1.000					
WU63	NCR	0.882	0.882	1.000					
WU64	NCR	1.000	1.000	1.000					
WU65	NCR	0.967	0.967	1.000					

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