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Techno-economic Efficiency of Water Utilities: a Peer-Evaluation Estimation

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Abstract
Water utilities provide water and sanitation services in monopolistic conditions. Hence, assessing their performance through benchmarking is crucial for proper regulation. This research addresses the limitations of self-evaluation Data Envelopment Analysis (DEA) models commonly used for benchmarking water utilities' efficiency. Given that these models often lead to overestimated efficiency scores, our study introduces a cross-efficiency analysis framework integrating both self and peer-evaluation perspectives. This innovative approach, applied to a representative sample of Chilean water utilities, uniquely considers unplanned water supply interruptions and sewerage blockages as undesirable outputs, emphasizing service continuity. Average techno-economic efficiency scores based on self-evaluation, and peer-evaluation were 0.681 and 0.388, respectively. Hence, significant techno-economic efficiency overestimations in self-evaluation scores are evident, with implications for regulatory challenges and potential service quality compromises. The data also highlights a considerable opportunity for improvement in water and sanitation continuity in Chilean water utilities. The findings not only shine a spotlight on the inherent biases of prevalent benchmarking techniques but also highlight a substantial avenue for bolstering water and sanitation service continuity within water utilities.

Keywords Techno-economic efficiency · Water utilities · Quality of service · Continuity · Data envelopment analysis · Cross-efficiency

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1 Introduction

The United Nations (UN) has formally recognized access to water and sanitation as fundamental human rights (UN 2010). Furthermore, the Sustainable Development Goal 6 commits to ensuring “universal and equitable access to safe and affordable drinking water for all by 2030” (target 6.1) and aims to “provide adequate and equitable sanitation and hygiene for all, ending open defecation by 2030” (target 6.2) (UN 2015). Water utilities, responsible for delivering these essential services, often operate under monopolistic conditions. This is largely due to significant fixed costs and the inherent economies of scale in the water sector (Marques 2011). Given these conditions, the water industry lacks inherent incentives to optimize its performance or drive innovation (Berardi et al. 2021). Recognizing these challenges, many countries have implemented regulatory measures to oversee water utilities. This regulatory oversight aims to safeguard consumer interests, establish sustainable water tariffs, and introduce mechanisms to motivate efficiency improvements within the sector (IWA 2015; Neverre 2024).

Benchmarking is recognized as a potent tool for gauging the performance of regulated water utilities (De Witte and Marques 2012). Moreover, it is a crucial component for constructing effective regulatory frameworks (Vilarinho et al. 2023; Buendía Hernández et al. 2024). Given its importance, there has been an increase in scientific research over the past two decades focused on evaluating the performance of water utilities (Goh and See 2021). Comprehensive literature reviews carried out by Cetrulo et al. (2019) and Goh and See (2021) have highlighted that data envelopment analysis (DEA) emerges as the predominant method for evaluating water utilities’ performance, surpassing the use of the stochastic frontier analysis approach. DEA’s preference can be attributed to several salient features: (i) DEA permits the amalgamation of various input and output combinations, yielding a scalar measurement of relative efficiency on the production frontier (Nithammer et al. 2022); (ii) it does not require to specify the functional form for the production function, offering adaptability in evaluations (Walker et al. 2020) and; (iii) it allows incorporating undesirable outputs, which might stem from the service quality deficiencies presented by water utilities (Molinos-Senante et al. 2015).

Despite the numerous methodological merits of the DEA method, prior investigations in this domain have predominantly shared a recurring constraint: they primarily relied on a self-evaluation DEA perspective. This implies that each water utility determines the weights that bolster its efficiency score to its utmost potential (Cetrulo et al. 2019). An inherent drawback of this approach is that multiple water utilities might be classified as efficient, making it arduous to further distinguish among them (Chen et al. 2023). Additionally, there’s a propensity for self-evaluation DEA models to overestimate efficiency scores. From a policymaking perspective, the self-evaluation DEA presents two main shortcomings: (i) absence of external benchmarking: it involves the omission of external validation via benchmarking against peer water utilities. Such comparative benchmarking is indispensable from a regulatory vantage point; (ii) overestimating efficiency scores through self-evaluation can inadvertently cast shadows over genuine avenues for performance amelioration in the water industry. Overestimation may lead to a complacent stance, with potential improvements remaining unexplored or unaddressed (Sala-Garrido et al. 2023).

In addressing the shortcomings of the self-evaluation DEA in assessing water utilities’ efficiency, the cross-efficiency DEA method emerges as a potent alternative. This technique melds the self-evaluation approach with peer-evaluation, furnishing a broader and more balanced analysis (Zhang et al. 2022). Through this combined evaluation, cross-efficiency DEA offers a grounded and pragmatic efficiency appraisal, shedding light on policy and performance enhancement avenues in the water domain (Medeiros et al. 2022). Whitin the DEA cross-efficiency models[1] we focus on those that allow for the integration of undesirable outputs. This is because we are interested in evaluating the techno-economic efficiency of water utilities integrating unplanned water supply interruptions and sewerage blockages as variables representing the lack of continuity in the provision of water and sanitation services. Even though service continuity is paramount in gauging service quality, past research incorporating these variables has been sparse (Cetrulo et al. 2019).

Building on the cross-efficiency framework proposed by Liao et al. (2022), the estimation of techno-economic efficiency scores can be bifurcated based on two distinct preferences: the water industry perspective and the water utility perspective. Firstly, water industry techno-economic performance (WITEP) approach treats all water utilities as a singular entity representing the industry in its entirety. Its chief objective is to augment the techno-economic efficiency of the collective water industry. This method is most apt when the evaluation's primary objective is to pinpoint avenues for enhancing water and sanitation service continuity across the sector. Secondly, water utility techno-economic performance (WUTEP) approach zeroes in on individual water utilities, seeking to optimize the techno-economic efficiency of each specific entity. By discerning between these two distinct approaches, cross-efficiency DEA offers a versatile and nuanced tool, adaptable to varied evaluation objectives within the water industry.

This paper sets out with dual objectives. Firstly, it evaluates the techno-economic efficiency of water utilities concerning the delivery of water and sanitation services, focusing on their continuity. Secondly, the paper contrasts the techno-economic efficiency self-evaluation method against the peer-evaluation approach, incorporating both WITEP and WUTEP estimates, with an aim to furnish pertinent insights for water regulators.

This study makes significant contributions to the field of techno-economic assessment of water utilities, particularly in the following aspects. This study stands out as one of the few that applies a cross-efficiency approach to estimate the efficiency of water companies. This approach extends beyond the traditional self-evaluation models commonly used in DEA. Moreover, to the best of our knowledge, it is the first study to directly compare self-evaluation and peer-evaluation efficiency metrics. This comparison highlights the limitations of conventional DEA models in assessing the performance of water utilities, offering a more nuanced understanding of efficiency. Secondly, the methodological approach employed in this study enables the estimation of both WITEP and WUTEP. This dual estimation is particularly relevant for decision-making in the context of water regulation. WITEP and WUTEP provide comprehensive insights into both the overall industry efficiency and the technical efficiency at the utility level. Finally, the integration of unplanned water supply disruptions and sewer blockages into the analysis as undesirable outputs offers a more holistic assessment of techno-economic efficiency, capturing nuances that are paramount for both utilities and end consumers.

[1] Some cross-efficiency DEA models are: (i) aggressive and benevolent (Doyle and Green 1994); (ii) neutral (Wang and Chin 2010); (iii) prospect (Liu et al. 2019) and; (iv) regret-rejoice (Jin et al. 2022).

2 Materials and Methods

The methodological approach consists of three main stages, as illustrated in Figure S1, which are described as follows:

2.1 Estimation of Techno-economic Efficiency of Water Utilities

Let´s assume that there are n water utilities using x_{ij} $(i = 1, \ldots, m)$ inputs (operational costs) to produce desirable outputs y_{rj} $(r = 1, \ldots, s)$ (water and sanitation services) and undesirable outputs z_{fj} $(f = 1, \ldots, h)$ (interruptions in the services), techno-economic efficiency scores based on self-evaluation for each utility were estimated by solving Model (1) (Banker et al. 1984):

$$
\begin{array}{l}
\theta^*_{dd} = Max \sum_{r=1}^{s} u_{rd} y_{rd} - \sum_{f=1}^{h} w_{fd} z_{fd} \\
subject\ to: \\
\sum_{i=1}^{m} v_{id} x_{id} = 1; \\
\sum_{r=1}^{s} u_{rd} y_{rj} - \sum_{f=1}^{h} w_{fd} z_{fj} - \sum_{i=1}^{m} v_{id} x_{ij} \leq 0, \quad j = 1, \ldots, n; \\
\sum_{r=1}^{s} u_{rd} y_{rj} - \sum_{f=1}^{h} w_{fd} z_{fj} \geq 0, \qquad j = 1, \ldots, n; \\
\forall\ v_{id},\ u_{rd},\ w_{fd} \geq 0;
\end{array}
\tag{1}
$$

where $v_{id},\ u_{rd},\ w_{fd}$ are the weights for inputs, desirable outputs and undesirable outputs, respectively.

For peer-evaluation, techno-economic efficiency was assessed from two distinct angles: the broader water industry perspective (WITEP) and the more specific water utilities perspective (WUTEP). This dual-pronged approach offers regulators a more comprehensive toolkit, tailored to the primary objective of their benchmarking efforts. WITEP is grounded in the regulator's focus on minimizing interruptions on water and sanitation services. In essence, it emphasizes enhancing the continuity of services across the entire water industry. This is done under the assumption that the economic performance of the scrutinized water utilities remains stable. To derive WITEP scores, the subsequent model is employed (Liao et al. 2022):

$$
\begin{array}{l}
Min \sum_{f=1}^{h} w_{fd} \sum_{j=1}^{n} z_{fi} \\
subject\ to: \\
\sum_{i=1}^{m} v_{id} \sum_{j=1}^{n} x_{ij} = 1; \\
\sum_{r=1}^{s} u_{rd} y_{rj} - \sum_{f=1}^{h} w_{fd} z_{fj} - \sum_{i=1}^{m} v_{id} x_{ij} \leq 0, \quad j = 1, \ldots, n; \\
\sum_{r=1}^{s} u_{rd} y_{rj} - \sum_{f=1}^{h} w_{fd} z_{fj} \geq 0, \quad j = 1, \ldots, n; \\
\sum_{r=1}^{s} u_{rd} y_{rd} - \sum_{f=1}^{h} w_{fd} z_{fd} - \theta^*_{dd} \sum_{i=1}^{m} v_{id} x_{id} = 0, \\
\forall\ v_{id},\ u_{rd},\ w_{fd} \geq 0;
\end{array}
\tag{2}
$$

where θ^*_{dd} is the techno-economic efficiency score of water utility$_d$ based on self-evaluation, i.e., techno-economic efficiency score from Model (1).

While WITEP emphasizes the continuity of services across the entire water industry, WUTEP adopts a more utility-specific approach. With WUTEP, the primary concern for the decision maker is the minimization of water and sanitation services for each individual water utility, assuming the economic performance of these utilities remains consistent. By this methodology, the water regulator aims to pinpoint the pinnacle of techno-economic efficiency for each utility, in isolation from the broader water industry's performance. To determine WUTEP scores, the following model is applied (Liao et al. 2022):

$$\begin{aligned}
&Min\ \delta \\
&subject\ to: \\
&\textstyle\sum_{i=1}^{m} v_{id}x_{id} = 1; \\
&\textstyle\sum_{r=1}^{s} u_{rd}y_{rj} - \sum_{f=1}^{h} w_{fd}z_{fj} - \sum_{i=1}^{m} v_{id}x_{ij} \leq 0, \quad j = 1,\ldots,n; \\
&\textstyle\sum_{r=1}^{s} u_{rd}y_{rj} - \sum_{f=1}^{h} w_{fd}z_{fj} \geq 0, \quad j = 1,\ldots,n; \\
&\textstyle\sum_{r=1}^{s} u_{rd}y_{rd} - \sum_{f=1}^{h} w_{fd}z_{fd} - \theta_{dd}^{*} \sum_{i=1}^{m} v_{id}x_{id} = 0, \\
&w_{fd}z_{fd} \leq \delta, \quad f = 1,\ldots,h; \\
&\forall\ v_{id}, u_{rd}, w_{fd} \geq 0;
\end{aligned} \tag{3}$$

As noted Liao et al. (2022), Models (2) and (3) are linear programming models and therefore, they can be solved directly. Moreover, Models (1), (2) and (3) assume variable returns to scale which allows for the inclusion of potential economies of scale during the assessment process.

2.2 Case Study

Ensuring the protection of customer interests, the pursuit of efficiency, and the establishment of water tariffs, water utilities in Chile are governed by the Superintendencia de Servicios Sanitarios (SISS). This body acts as the national regulator for urban water services in Chile. From a governance standpoint, every water utility, regardless of its ownership structure, adheres to the same regulatory framework termed the "model-firm regulation" approach (Donoso 2015). This model implies that water tariffs are determined on the presumption of the water utility operating at economic efficiency. The tariffs are rooted in the principle of full cost recovery, encompassing the operational costs of the water utilities and their maintenance and investment needs. However, an area not directly addressed within this tariff-setting procedure is the service quality. Factors such as interruptions in water and sanitation services that a utility may have encountered during the preceding tariff duration are not explicitly integrated into the tariff determination process (Mocholi-Arce et al. 2023).

Techno-economic efficiency evaluations were carried out on 23 Chilean water utilities, which collectively serve 96% of the urban people at the national level. In urban areas, almost universal access is evident with drinking water coverage at 99.9% and wastewater treatment services at 90% (SISS 2022). Of the 23 water utilities assessed, a significant majority, 22 in total, are managed by private entities (Figure S2 shows the main cities in Chile and its water utility). Breaking it down, 63% (or 14 out of 22) operate as fully private water utilities, while the remaining 37% (or 8 out of 22) function as concessionary water utilities. These private utilities cater to approximately 92.5% of the urban population in Chile. On the other hand, a single public water utility exists, extending its services to a mere 3.5% of the urban populace.

The evaluated water utilities display considerable variability in size, both in terms of the volume of drinking water they handle and the number of customers they serve. The volume of drinking water processed annually by these utilities spans from as little as 488,000 m^3 to a substantial 454,369,000 m^3. In terms of customer base, these utilities cater to anywhere between 5,653 households to a significant 2,115,230 households. Given this wide range of operational scales, it underscores the importance of calculating techno-economic efficiency scores with a consideration for variable returns to scale, as observed in models (1), (2), and (3).

To evaluate the techno-economic performance of Chilean water utilities, several variables have been considered. They have been informed by previous research (Cetrulo et al. 2019; Goh and See 2021; Maziotis et al. 2023) and data availability. The two inputs considered were: (i) annual operating costs: the total yearly costs, denominated in million Chilean pesos, associated with each water utility for the provision of water and sanitation services. Notably, staff costs are excluded from this parameter and; (ii) number of workers: this refers to the total number of employees engaged by each water utility.

Given that techno-economic efficiency encompasses both drinking water and sanitation services, the selected desirable and undesirable outputs integrate elements from both sectors. Two desirable outputs were included to assess techno-economic efficiency: (i) quality-adjusted volume of drinking water supplied expressed in m^3/year. This metric is derived by multiplying the annual volume of water distributed by each utility by its respective drinking water quality index. Hence, this provides a quality-weighted volume assessment and; (ii) customers with access to quality-adjusted wastewater treatment services. This output involves multiplying the number of customers availing wastewater treatment services by a wastewater treatment quality index that has been determined for each utility. Both quality indices (for drinking water and wastewater treatment) are computed for individual water utilities by the SISS. These indices can have values ranging from 0 to 1. A score of 1 denotes optimal performance, implying that the utility has not shown any shortcomings with respect to either drinking water quality or wastewater treatment standards (SISS 2022). Consequently, if a water utility faces issues regarding the quality of its services, its desirable outputs see a reduction.

In terms of undesirable outputs, the following variables have been considered: (i) duration of unplanned drinking water supply interruptions measured in hours/year.; (ii) duration of sewerage system blockages expressed in hours/year.Like the previous metric, only blockages for which the water utility holds responsibility are included in this assessment.

Statistical information was provided by SISS for 2022 and it is shown in Table 1.

3 Results

3.1 Techno-economic Efficiency Assessment Based on Self-evaluation and Peer-Evaluation

Figure 1 presents the techno-economic efficiency scores for the 23 surveyed Chilean water utilities. Using the self-assessment method (Model 1), the average techno-economic efficiency is calculated to be 0.689. From a peer-evaluation standpoint, the average scores are 0.581 for WITEP (Model 2) and 0.388 for WUTEP (Model 3). The discrepancy in these techno-economic efficiency scores underscores the potential bias of overestimation inherent in self-evaluations. However, this bias is addressed by the cross-efficiency techniques, WITEP and WUTEP. To determine the statistical significance of the differences in techno-economic efficiency between self and peer evaluations, the non-parametric Mann-Whitney

Table 1 Statistical information of Chilean water utilities for 2022

Variables	Average	Std. Dev	Minimum	Maximum
Operational_costs (millon CLP/year)	49,953	66,371	1,531	280,983
Workers (number)	773	1,040	41	4,451
Volume of water (1000 m^3/year)	52,240	96,051	488	454,369
Index of water quality	0.977	0.056	0.740	1.000
People with wastewater service (number)	827,350	1,612,721	7,381	7,457,084
Index of wastewater treatment quality	0.980	0.026	0.904	1.000
Unplanned water interruptions water (hours/year)	1,177	1,844	25	6,772
Sewerage blockages (hour/year)	7,314	15,064	10	69,435

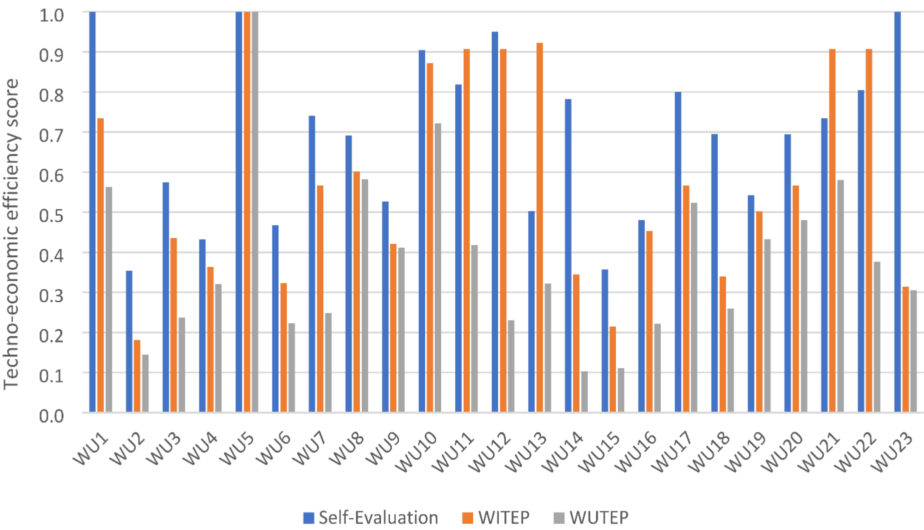

Fig. 1 Techno-economic efficiency scores of Chilean water utilities based on self-evaluation and peer-evaluation (WITEP and WUTEP)

test was employed. The test sought to verify if the efficiency scores from both evaluation methods originate from a common population. According to Buta et al. (2023), a p-value of 0.05 or lower would indicate a 95% confidence in rejecting the null hypothesis. With an obtained p-value of 0.032, it is verified that techno-economic efficiency scores from self-evaluation and peer-evaluations significantly differ.

Self-evaluation tends to result in performance overestimation, as demonstrated by the techno-economic efficiency of water utilities shown in Fig. 1. Through self-assessment, 3 of the 23 water utilities, which is 13.04%, are deemed techno-economic efficient. This means they lie on the efficient production frontier, marking them as top performers. However, when using the peer-evaluation method, both WITEP and WUTEP, determine that only a single utility meets the techno-economic efficient criteria. Consequently, this specific utility sets the benchmark for the remaining 22 utilities examined in this research. This benchmark utility is a fully private entity operating within the Metropolitan Region of Santiago. It is a medium-sized utility, supplying approximately 60 million m^3 of water annually at a mean cost of 704 CLP/year, i.e., 0.75 €/m^3. Noteworthy is its exceptional performance in water quality and wastewater treatment quality, with index scores of 0.992 and 0.986, respectively. Additionally, this utility experiences significantly fewer unplanned water disruptions and sewer blockages compared to the Chilean water industry average.

Past studies on the techno-economic efficiency scores of Chilean water utilities have yielded varying results, contingent on the year of analysis, the methodology employed, and the variables considered (Maziotis et al. 2023). Sala-Garrido et al. (2022) calculated an average operational and quality-adjusted efficiency score at 0.964. However, this study overlooked the impact of quality indexes on desired outputs and did not factor in sewerage obstructions as a service quality variable. Research conducted by Molinos-Senante et al. (2022) and Mocholi-Arce et al. (2022) revealed average efficiency scores that align more closely with our results, registering at 0.595 and 0.527 respectively. However, their analyses also excluded sewerage obstructions from consideration. Efficiency assessments of Chilean water utilities by past studies have been approached from a self-evaluation perspective. In contrast, our calculations, which were based on peer-evaluation methods (WITEP and WUTEP), consistently returned considerably lower techno-economic efficiency scores. This underscores the inherent tendency for self-evaluation to yield inflated efficiency scores.

The techno-economic efficiency score is scaled between 0.0 and 1.0, enabling the estimation of potential improvements in water and sanitation service continuity for each utility, based on current interruption durations and efficiency scores (Sala-Garrido et al. 2023) as shown in Fig. 2. Using self-evaluation, it is estimated that Chilean water utilities, on average, need to reduce service interruptions by 1,817 h per year to be techno-economic efficient. Given that the peer-evaluation method yields lower efficiency scores, there is a more

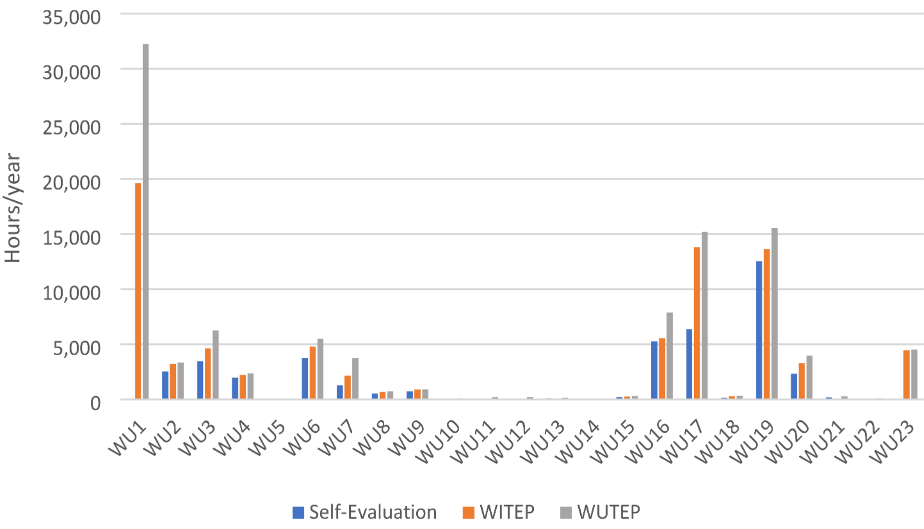

Fig. 2 Potential improvement in water and sanitation continuity for Chilean water utilities

significant scope for improvement. On average, reductions of 3,476 h/year and 4,390 h/year are needed, according to WITEP and WUTEP evaluations, respectively. Figure 2 highlights substantial variances among the water utilities. These disparities are attributed to the differences in techno-economic efficiency scores and the existing durations of water and sanitation service interruptions. Thus, it is evidenced the need of adopting different strategies by water utilities to improve continuity of service.

3.2 Techno-economic Efficiency Assessment Based on WITEP and WUTEP

When juxtaposing the techno-economic efficiency scores of WITEP against WUTEP, Fig. 3 delineates that WITEP scores consistently surpass those of WUTEP across all water utilities under examination. This suggests that optimizing global techno-economic efficiency simultaneously promotes the enhancement of techno-economic efficiency for individual utilities. This outcome emerges from WITEP's endeavor to prioritize global techno-economic efficiency, leading to the generation of peer-evaluation efficiency scores from WITEP that frequently outperform those from WUTEP (Sala-Garrido et al. 2023). The correlation coefficient between the techno-economic efficiency scores of WITEP and WUTEP stands at 0.65, indicating a moderate level of correlation between the two metrics. Furthermore, Fig. 3 showcases pronounced variations among the water utilities, emphasizing that the selection between WITEP and WUTEP scores as the preferable metric hinges on the specific objectives of the benchmarking procedure.

To further analyze differences between WITEP and WUTEP, Fig. 4 shows techno-economic distributions based on both metrics. It is evident that under the orientation of WUTEP, only two water utilities have an efficiency greater than 0.6 and therefore, 21 of the 23 utilities have an improvement potential greater than 40%. On the other hand, in the case of WITEP, 9 companies have a techno-economic efficiency greater than 0.6, which shows that nationally the continuity of water and sanitations services is relatively good, but it is at the individual level where some utilities need to introduce substantial improvements.

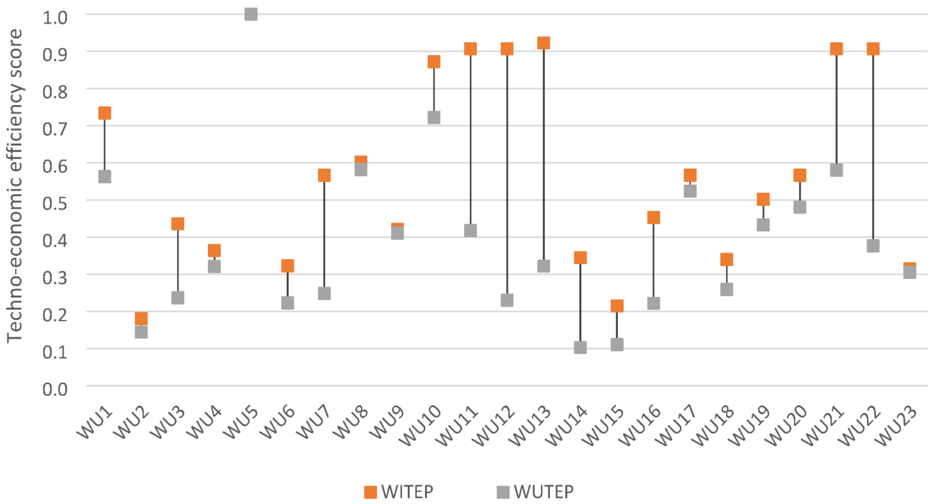

Fig. 3 Techno-economic efficiency scores of Chilean water utilities based on industry (WITEP) and utilities (WUTEP) orientations

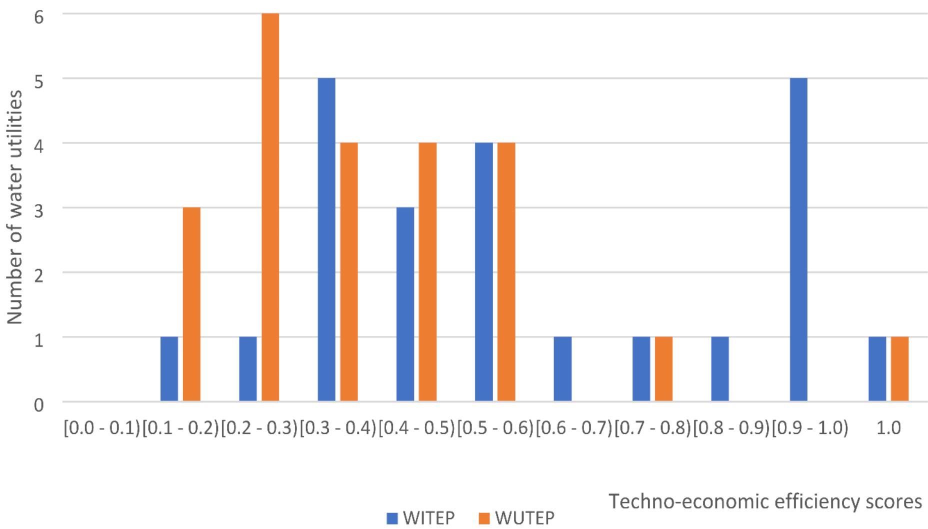

Fig. 4 Distribution of techno-economic efficiency scores of Chilean water utilities based on WITEP and WUTEP estimations

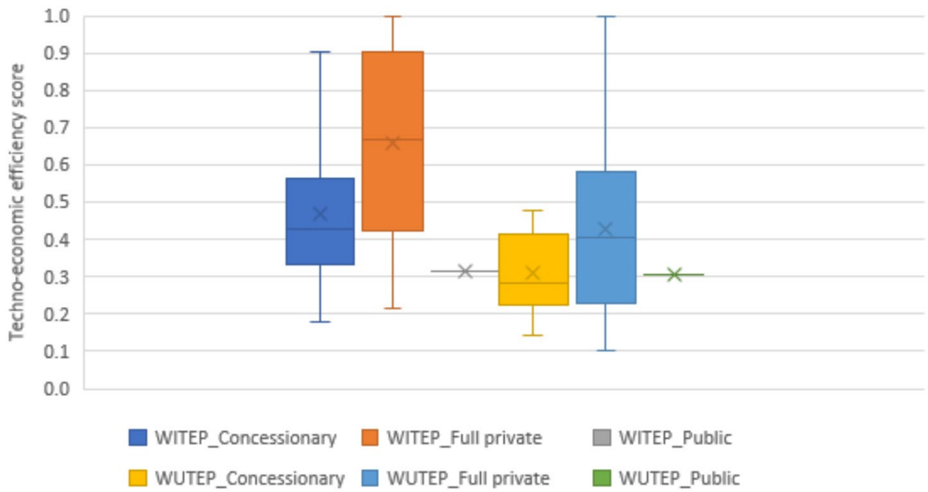

Fig. 5 Statistics of techno-economic efficiency scores grouping by water utilities´ ownership

Given that the sample of water utilities examined in this study encompasses various ownership structures, including 14 fully private, 8 concessionary, and 1 public utility, Fig. 5 delineates the WITEP and WUTEP score statistics respective to each ownership category. For both WITEP and WUTEP assessments, the public utility consistently lags behind in performance, predominantly attributed to its high incidence of sewerage blockages. When contrasting fully private utilities with concessionary ones, techno-economic efficiency scores suggest that fully private utilities outperform their concessionary counterparts. This disparity becomes even more pronounced in the WITEP evaluations, reinforcing the idea that, from a global standpoint, fully private utilities in Chile predominantly define the efficient production frontier (Maziotis et al. 2021).

4 Discussion

Because techno-economic efficiency assessment conducted in this study integrates unplanned water supply interruptions and sewerage blockages as undesirable outputs, some potential actions that water utilities could adopt to improve water and sanitation continuity and therefore, techno-economic efficiency are as follows: (i) regular maintenance: schedule periodic checks of pipelines, valves, pumps, and other equipment; (ii) infrastructure upgrade: replace old, corroded, and leaking pipelines. It should be noted that on average the replacement rate of water and sanitation pipes in Chile is 0.30% and 0.22%, respectively. It is a very low rate considering that a renewal rate of 2% would imply renewing the entire network in a horizon of approximately 50 years (SISS 2022); (iii) adopt advanced technologies: implement smart sewer systems with sensors to detect blockages early and predictive analytics to identify potential problem areas before blockages occur (Li et al. 2023); (iv) separate stormwater and sewage systems: ensure that stormwater is diverted away from the sewage system to prevent overflows and blockages. Currently in Chile, large stormwater volumes and discharges cause urban flooding and sewerage blockages (Simon et al. 2023).

From a regulatory standpoint, the tendency to overestimate techno-economic efficiency through self-evaluation can pose multiple problems and challenges for the water sector: (i) Inadequate capital allocation: techno-economic efficiency overestimation may suggest that the current infrastructure is more suitable than it really is, which might lead to underinvestment in necessary upgrades. This could lead to insufficient funds being allocated to vital upgrades. In the context of the Chilean water sector, this concern is highlighted by the previously reported slow replacement rate of water and sanitation infrastructure; (ii) Relaxed regulatory oversight: if utilities are mistakenly perceived as highly efficient due to overestimation, regulatory bodies might set less stringent standards, believing that the status quo is acceptable or even commendable; (iii) Compromised service quality: when utilities operate under the misconception that their services are of higher quality than they are in reality, certain areas needing improvement may be overlooked, ultimately diminishing the overall quality of service; (iv) Stagnation in innovation: if water utilities believe their current technologies and methods are more efficient than they actually are, they may not invest in researching or adopting new, more effective solutions; (v) Tariff discrepancies: water and sanitation tariffs in Chile are set based on the efficient water utility model (SISS 2022). Overestimating performance can lead to the imposition of inflated tariffs, burdening consumers more than necessary; (vi) Stakeholder misunderstanding: overly optimistic views of techno-economic efficiency can misguide a range of stakeholders, from investors and governmental entities to the general public. This can result in decisions that do not truly reflect the utility's genuine capabilities or needs, potentially leading to suboptimal outcomes. Such challenges underline the importance of objective, accurate, and holistic techno-economic evaluations in the water and sanitation sector.

5 Conclusions

Benchmarking water utilities is crucial for enhancing efficiency and safeguarding consumer interests, especially given the monopolistic conditions under which these utilities operate. While there is an extensive body of research on this subject, a common thread among previous studies is their reliance on self-evaluation DEA models for efficiency estimation. Such an approach overestimates efficiency scores, as weights are allocated in a manner that maximize these scores. This can lead to the classification of multiple utilities as efficient, obfuscating true differentiators among them.

In an endeavor to address the limitations of self-evaluation DEA, our research introduces and applies a cross-efficiency analysis framework. This not only encompasses the traditional self-evaluation but also integrates a peer-evaluation perspective, offering a more balanced and comprehensive assessment. What further sets this study apart is its incorporation of unplanned water supply interruptions and sewerage blockages as undesirable outputs. Hence, this study assesses the techno-economic efficiency of water utilities with emphasis on the continuity of water and sanitation services.

This study delves into a representative sample of Chilean water utilities, spanning fully private, concessionary, and public utilities. When evaluating their techno-economic efficiency, the average scores derived from self-evaluation, WITEP, and WUTEP are 0.689, 0.581, and 0.388, respectively. The evident overestimation in efficiency scores stemming from self-evaluation poses potential challenges from a regulatory standpoint. Such inflated evaluations can lead to insufficient investment in essential infrastructure, a relaxation of service quality standards, and/or the imposition of unwarranted high tariffs for water and sanitation services.

Additionally, the results underscore a significant opportunity for Chilean water utilities to enhance service continuity, particularly when viewed from an individual utility's perspective. When dissecting the performance based on ownership structure, both WITEP and WUTEP evaluations indicate that fully private utilities outshine their counterparts in terms of efficiency. In stark contrast, the public utility emerges as the entity with the most substantial scope for enhancement. This research offers critical insights, particularly for regulators and policymakers, to address and rectify these disparities in performance and service delivery.

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Data Availability Data will be available upon request.

Declarations

Ethical Approval This article contains no studies with human participants nor animals.

Consent to Participate All authors consented to participate.

Consent to Publish All authors read and approved the final manuscript. All authors consent to publish the present study.

Competing Interests The authors have no competing interests to declare that are relevant to the content of this article.

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