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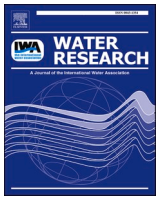

Exploring water affordability through subsidy policies

Thalita Salgado Fagundes [a,b,c,*], Rui Cunha Marques [b], Diogo Filipe da Cunha Ferreira [d], Tadeu Fabricio Malheiros [c]

[a] Civil Engineering Research and Innovation for Sustainability (CERIS), Instituto Superior Técnico, University of Lisbon, Av. Rovisco Pais, 1049-001 Lisbon, Portugal
[b] Lusófona University, RCM2+, Campo Grande 376, 1749-024 Lisboa, Portugal
[c] Department of Hydraulics and Sanitation, University of São Paulo, Avenida Trabalhador são-carlense, 400, São Carlos-SP, Brazil
[d] CEGIST, Instituto Superior Técnico, Universidade de Lisboa, Av. Rovisco Pais, 1, 1049-001 Lisbon, Portugal

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ABSTRACT

Access to clean water and sanitation is a fundamental human right, yet millions of people worldwide, particularly in low- and middle-income countries, face affordability barriers. This study evaluates Brazil's new social tariff policy for water supply and sanitation, enacted in 2024 through Law No 14,898, which introduces a nationally mandated social tariff, representing a rare example of nationwide affordability intervention in the sector. Using data from the Ministry of Social Development, the study examines three scenarios reflecting potential beneficiaries and their financial impacts on utilities revenue and on non-beneficiaries' bills. Results reveal significant regional disparities in affordability and the financial strain placed on utilities, particularly in economically disadvantaged states in the north. Cross-subsidization emerges as the primary funding mechanism, yet this approach risks exacerbating affordability issues for non-beneficiary households, as observed in the study. This research underscores the critical need for affordability analyses in public policies, highlighting the importance of equitable and sustainable subsidy structures to improve water access while maintaining the financial viability of utilities.

1. Introduction

Access to clean water supply and sanitation (WSS) is a fundamental human right, as underscored by the United Nations' Sustainable Development Goal (SDG) 6, which aims to ensure the availability and sustainable management of water and sanitation for all. Despite this global commitment, billions of people, particularly in low- and middle-income countries, continue to face challenges in accessing adequate WSS services. These challenges are not restricted to physical connections, but often rooted in issues of affordability, especially for low-income households. The lack of affordable water access not only exacerbates inequalities but also poses serious public health risks. To bridge this gap, governments and water utilities employ various mechanisms designed to reduce the financial burden on customers while promoting the universal provision of WSS services (L. A. Andres et al., 2019; Narzetti and Marques, 2020). Some researchers have classified main affordability interventions into categories, such as rate structure designs, water efficiency programs, bill assistance and crisis relief (Pierce et al., 2021).

The most common approaches rely on subsidies and can be categorized into two main types: supply-side and demand-side subsidies (Marques, 2024). Supply-side subsidies target water service providers, offering financial support for the construction, expansion, and maintenance of water infrastructure. Such subsidies aim to lower the capital costs for utilities, which, in turn, is expected to reduce the price of water for end-users. Examples include grants for infrastructure projects, interest-free loans, and fiscal incentives for water utilities. This has led to extensive improvements in water accessibility. Demand-side subsidies directly benefit customers, especially low-income households, by reducing the cost they pay for water consumption. These subsidies can take the form of direct cash transfers, vouchers, or price reductions on water bills. These measures aim to protect vulnerable populations but often result in unintended benefits for wealthier customers, as observed with increasing block tariffs (IBTs) (Angel-Urdinola and Wodon, 2007; Komives et al., 2005; Pinto and Marques, 2015b). Each type of subsidy

* Corresponding author at: Civil Engineering Research and Innovation for Sustainability (CERIS), Instituto Superior Técnico, University of Lisbon, Av. Rovisco Pais, 1049-001 Lisbon, Portugal.
E-mail addresses: thalita.fagundes@tecnico.ulisboa.pt (T.S. Fagundes), rui.marques@ulusofona.pt (R.C. Marques), diogo.cunha.ferreira@tecnico.ulisboa.pt (D.F.C. Ferreira), tmalheiros@usp.br (T.F. Malheiros).

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has its merits and challenges. While supply-side subsidies promote long-term investment and infrastructure development, demand-side subsidies try to ensure that water services are affordable for vulnerable populations.

Within the broader framework of demand-side subsidies, water tariff subsidies have emerged as a prominent tool used by governments and water utilities worldwide to improve access to clean water for low-income households, reducing inequality, and ensuring the financial sustainability of water utilities. Water tariff subsidies are then used as a financial mechanism aimed at lowering the cost of water consumption for households, typically through differentiated pricing structures. The most common approach is the implementation of IBTs, where the unit price of water increases with higher consumption volumes. The rationale behind this approach is that poorer households, which generally consume less water, will benefit from lower rates, while wealthier households, which consume larger quantities, pay higher rates. In addition, ensuring a minimum volume of water at a reduced price theoretically upholds the human right to water. However, empirical evidence has shown that IBTs often fail to effectively target low-income households (Angel-Urdinola and Wodon, 2007; Wodon et al., 2003). This is because many poor households do not have formal water connections and are thus excluded from the benefits of subsidized tariffs. Moreover, wealthier households may consume water at levels that qualify for lower tariff rates, further distorting the intended social equity goals of the IBT system.

A significant issue with cross-subsidization through IBTs is that it relies on the assumption that low-income households consume less water than high-income households. While this assumption holds true in some contexts, it fails in many others. Low-income households may have larger family sizes, leading to higher water consumption that pushes them into higher tariff blocks. Conversely, high-income households with fewer members may benefit from lower tariffs if their consumption remains within the "lifeline" block. As a result, the subsidies intended to support low-income households may instead benefit wealthier households, undermining the policy's equity objectives (Angel-Urdinola and Wodon, 2007; Cardenas and Whittington, 2019; Fuente et al., 2016; Nauges and Whittington, 2017; Pinto and Marques, 2015b).

To address these shortcomings, several countries have improved their water tariff and/or subsidy policies to better target subsidies toward vulnerable groups, through national or local initiatives. Chile has enacted the Law No 18,778 in 1989, introducing a means-tested water subsidy scheme in the country. Funded by general taxation, the benefit covers between 25 and 85 % of the monthly WSS bill for the first 13 m^3, and the beneficiaries are identified using a sophisticated targeting instrument developed for the general welfare system (Errázuriz and Gómez-Lobo, 2024). Another example is the case of Lima and Callao, in Peru, where the WSS utility implemented an important reform in 2017 introducing a different tariff for customers residing in poor blocks and reducing the lifeline block from 25 to 20 m ^{3}. A study showed that following the reform, poor households received subsidies that were 45 % higher than those granted to non-poor users, based on an average consumption of 14 m^3, which corresponds to the typical usage of subsidy-eligible customers (Gómez-Lobo et al., 2023). The reform effectively shifted the subsidy structure from a regressive to a progressive model, allowing low-income households to benefit 22 % more compared to a randomly allocated subsidy system (Gómez-Lobo et al., 2023). Brazil, for instance, recently enacted in June 2024 the new WSS social tariff policy – Law No 14,898. This policy seeks to augment the access to discount by vulnerable families setting explicit criteria for identifying eligible households and requiring regulators and utilities to automatically apply this deduction, using the same national data source – the platform *Cadastro Unico (*CADUnico*),* which identifies and characterizes low-income families residing throughout the entire national territory.

However, many of the initiatives lack regular and robust affordability assessments, which are crucial in all contexts but especially critical when tariff and cross-subsidization are involved. Affordability is commonly defined as the ability of households to pay for services without compromising other basic needs (WHO and UNICEF, 2021). Although disagreements over the definition of what would be an affordable bill remain in the literature, policymakers and practitioners typically assess the proportion of household income spent on water bills. International benchmarks suggest that water expenditures should not exceed 3–5 % of household income (Fagundes et al., 2023; Martins et al., 2016; WHO and UNICEF, 2021). However, in many low- and middle-income countries, low-income households often pay a disproportionate share of their income on water, especially when they rely on informal water sources at higher prices (Cook et al., 2015; Nauges et al., 2015; Pattanayak et al., 2005).

Effective affordability analysis enables policymakers to identify vulnerable groups that are most in need of support (American Water Works Association, 2015; Banerjee et al., 2008; Fagundes et al., 2025; Komarulzaman et al., 2019; Martins et al., 2016; Mastracchio et al., 2020). In addition, it clarifies when cross-subsidization is no longer advisable, as it may substantially increase tariffs to other residential customers. Moreover, affordability studies can support evidence-based policymaking by informing the design of direct cash transfers, vouchers, or tariff subsidies that are better aligned with the needs of vulnerable populations. This approach allows for a more precise allocation of resources, ensuring that the subsidies reach those who need them most.

This paper focuses on one type of intervention to improve financial access of poorer households, by analyzing the implications of Brazil's new WSS social tariff law in terms of affordability. By examining the design and expected outcomes of this policy, the study seeks to provide insights into its potential to enhance the affordability of WSS services for vulnerable populations but also to increase WSS bill for almost-poor families due to cross-subsidization. Through this analysis, the study contributes to the ongoing debate on how to design water tariff structures that are both equitable and financially sustainable. By focusing on Brazil's initiative, considering its size and high inequality, this research provides valuable lessons for other countries seeking to reform their water subsidy systems.

This paper is organized as follows: after this brief introduction, Section 2 outlines the case study. Section 3 describes the research methodology applied. Section 4 presents and discusses the main topics addressed by the studies. The final section provides the concluding remarks and suggestions for further research.

2. Case study

Despite some progress in recent years, the Brazilian WSS sector still face challenges related to universal access, quality of service, and financial sustainability. As of recent estimates, approximately 85 % of Brazil's population has access to potable water through 64.4 million of connections, while only about 56 % have access to adequate sanitation services.[1] This disparity highlights the persistent inequalities in service coverage between urban and rural areas, as well as across different socioeconomic groups, where southern regions – states São Paulo, Rio de Janeiro, Minas Gerais, Santa Catarina, Paraná, e Rio Grande do Sul - and urban areas have better access to those services, as observed in Figs. 1 and 2.

The WSS sector in Brazil is characterized by a mix of public, private, and mixed-capital service providers. The largest share of services is managed by state-owned WSS companies (in Portuguese acronym, CESBs), which are responsible for service provision in multiple municipalities. Municipal water utilities also play a significant role, especially in smaller towns and rural areas. Additionally, there is growing

[1] https://www.gov.br/cidades/pt-br/acesso-a-informacao/acoes-e-programas/saneamento/snis/produtos-do-snis/painel-de-informacoes.

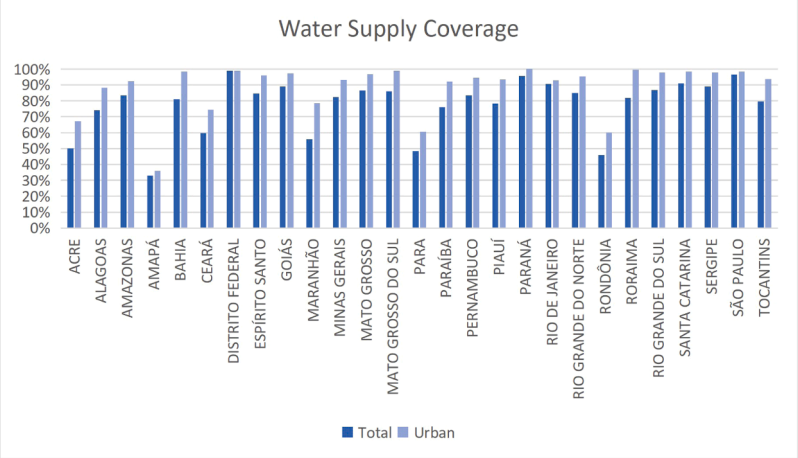

Fig. 1. Water Supply Access. Source: SNIS, year 2021.

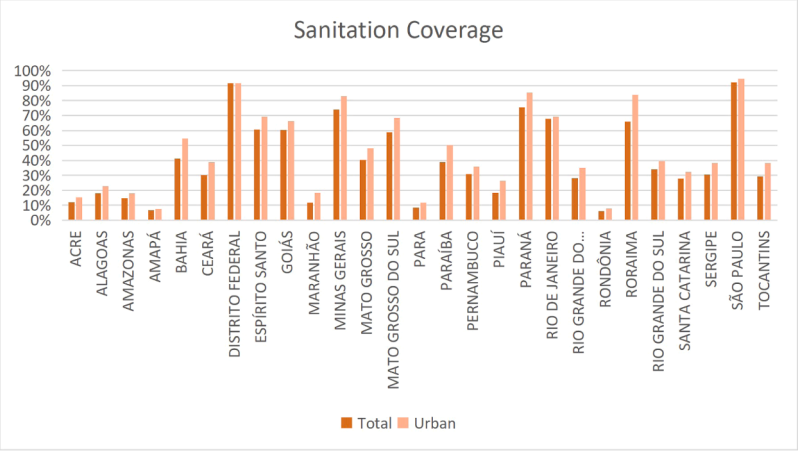

Fig. 2. Sanitation Network Access. Source: SNIS, year 2021.

participation from private operators, following regulatory changes from 2020. Public-private partnerships (PPPs) and concession contracts have become more prominent in the sector, especially in larger urban zones and within state-owned service areas.

The privatization wave gained momentum with Brazil's New WSS Framework of 2020 (Law No 14,026/2020), which sought to attract private investment and enhance efficiency through competitive bidding processes (Narzetti and Marques, 2021). The framework expanded the role of the National Water Agency (ANA), transitioning its focus from water resource regulation to overseeing WSS services as well. ANA now establishes regulatory guidelines and standards and harmonizes practices across subnational regulators in all states and, when applicable, municipalities.

A significant recent policy development is the 2024 enactment of Law No 14,898, implementing a national social tariff to aid vulnerable populations. Households earning up to half the national minimum wage, registered in the national social assistance database (*Cadastro Único - CADUnico*), or benefiting from the Continuous Cash Benefit Program (in Portuguese, *Benefício de Prestação Continuada* - BPC), which guarantees a national minimum wage for individuals over 65 years old or with disabilities, qualify for subsidized tariffs. In previous studies, it was found that although there is a common approach among state-owned companies, social tariffs do not reach vulnerable families as they are supposed to (the proportion of poor families receiving the benefit varies between 0 % to 41 % across Brazilian state-owned utilities) (Fagundes et al., 2025).

The law prescribes a minimum 50 % discount on the first 15 m^3 of WSS consumption for qualifying households. While Brazil predominantly employs increasing block tariffs (IBTs) with a minimum charge volume (typically 10 m^3), a shift toward two-part tariffs, combining fixed and volumetric charges, is underway. Although ambiguity persists regarding whether discounts apply to fixed charges, regulators have understood that such a discount must be applied to the entire WSS bill. In addition, while the law creates the National Fund for Water Access, which at the time of writing is not yet operational, it explicitly prioritizes cross-subsidization as financing mechanism. However, concerns have arisen regarding the reliance on cross-subsidization to fund these discounts, which could destabilize regions and cities with less or no economies of scale and/or robust economies. Additionally, while Law No 14,026/2020 sets targets to expand access to WSS services by 2033, Law No 14,898/2024 addresses affordability concerns exclusively for utility customers, i.e., already connected households. It does not allow utilities to use the mechanisms established by the law, such as the National Fund, to support network expansion, for example.

3. Material and methods

3.1. Scenarios adopted and potential beneficiaries

The new law mandates that all vulnerable families registered in the CADÚnico database are eligible for social WSS tariff benefits, which means mandatory tariff discounts provided by all utilities to customers

registered in CADÚnico and BPC. Vulnerable families are defined as those living below the poverty line, which in this program and several others is set at half the national minimum wage per capita. To remain eligible, family records in CADÚnico must be updated within the last 24 months.

Quantitative data for both CADÚnico and BPC beneficiaries were sourced from publicly available Ministry of Social Development websites. While the Ministry is working to unify these datasets, they remain separate as of the time of this study. These datasets are considered the most authoritative sources for estimating potential beneficiaries, although integration challenges persist, and discrepancies can introduce uncertainties.[2,3]

For this study, three scenarios were developed to capture the challenges faced by vulnerable Brazilian families in accessing WSS services discount. Predictably, many low-income families lack access to water supply and/or sanitation networks, which directly affects their eligibility for tariff discounts. Since these discounts are linked to WSS tariffs, the scenarios account for variations in families' access to these networks. The scenarios were constructed using data from the *Observatorio do Cadastro Unico*, the most recent available dataset, which, despite its utility, has certain limitations. Specifically, the dataset only indicates whether families have access to sanitation or drainage networks, without distinguishing between types of sanitation services, potentially introducing discrepancies. Moreover, access to water supply does not necessarily imply access to a utility-managed network. In this study, urban families with access to WSS services are assumed to already be customers of utilities but are not currently receiving tariff discounts (Scenarios 1 and 2). Rural families were assumed to be customers in the same proportion utilities' coverage rate reaches rural households – according to SNIS database (2021), 8.0 % and 2.5 % for water and WSS services, respectively, under local providers; 4.0 % and 1.9 % for water and WSS services, respectively, under state-owned companies. Additionally, Scenario 3, representing the total number of potential beneficiaries, was used only to calculate the total amount needed if all beneficiaries were connected to WSS services – which must happen by 2033 according to the new Brazilian WSS law (Law No 14,026/2020). It is worth mentioning that several service providers (particularly state-owned companies) already apply social tariffs. However, these existing programs often differ from the new national law in terms of eligibility criteria, discount levels, and overall reach, which remains limited (Fagundes et al., 2025). According to SNIS data, 3,246,756 households currently receive some form of discount, representing 17.6 %, 27.6 %, and 13.4 % of the total beneficiaries considered in Scenarios 1, 2, and 3, respectively. To account for this, we included an additional calculation estimating the required subsidies, assuming that the discounts already provided align with those mandated by the new law and that the beneficiaries are located in urban areas.

Detailed rural-urban breakdowns were available only for families listed in the CADÚnico database. For analysis purposes, BPC individual beneficiaries were converted into households, and assumed to have full access to WSS services across all scenarios and were distributed between rural and urban areas in the same proportion as CADÚnico families (18 % rural). Fig. 3 illustrates the scenarios adopted in this study.

3.2. Discount

The calculation of potential monthly discounts for social tariffs was carried out systematically for each scenario and each city, based on the number of potential beneficiaries, distinguishing between state-owned WSS companies and local WSS service providers. The results are displayed in terms of states, combining both types of utilities. The methodology involved the following steps:

a) Water Consumption Estimation: Average per capita water consumption for each city was obtained from the SNIS database (2021), while household size data were derived from the 2022 Census. These figures were combined to estimate total water consumption at the household level. Due to the unavailability of detailed data on household size among low-income populations in the 2022 Census, a sensitivity analysis was conducted by varying water consumption levels by ±20 %.
b) Water Bill: Using the water consumption estimation from previous item, WSS bills were calculated. For local service providers, the average WSS tariff from SNIS database (2021) was doubled to account for wastewater services (assuming they provide and charge for both services). For state-owned companies, bills were calculated using individual methodologies published on their respective websites, as of October 2024.
c) Scenario-Specific Assumptions: Scenario 2 and Scenario 3 assume that families are charged tariffs for both WSS services, while Scenario 1 considers that families are only charged for water supply services, excluding sanitation. As previously noted, Scenarios 1 and 2 assume that all urban and partially rural potential beneficiaries are already utility customers. However, this assumption may not hold due to the limitations and inaccuracies in data from the Ministry of Social Development and the gap between WSS network coverage and actual household connections, as utilities report service availability based on network presence, regardless of whether households are physically connected (2025 national guidelines are under review to change this situation).

Some state-owned companies have been shifting from a pure IBT model to a two-part tariff, comprising fixed and variable IBT components. While the law does not explicitly specify whether discounts apply to both components, this study assumed full application based on insights from the national regulator ANA. The discount calculations were performed using Eqs. (1) to 3.

$$\text{Discount S1(BRL)} = [(\text{WS bill})t0 - (\text{WS bill})t1] * \left(\text{CADUnico beneficiaries S1} + \left(\frac{\text{BPCbeneficiaries}}{\text{Household size}}\right)\right) \quad ((1))$$

$$\text{Discount S2(BRL)} = [(\text{WSS bill})t0 - (\text{WSS bill})t1] * \left(\text{CADUnico beneficiaries S2} + \left(\frac{\text{BPCbeneficiaries}}{\text{Household size}}\right)\right) \quad ((2))$$

$$\text{Discount S3(BRL)} = [(\text{WSS bill})t0 - (\text{WSS bill})t1] * \left(\text{CADUnico beneficiaries S3} + \left(\frac{\text{BPCbeneficiaries}}{\text{Household size}}\right)\right) \quad ((3))$$

Where:

WSS bill = The product of the WSS tariff, SNIS water consumption per capita, and household size.

WS bill = The product of the WS tariff, SNIS water consumption per capita, and household size.

T0 = Tariff before the implementation of the law

T1= Tariff after the implementation of the law

S1, S2, S3 = Scenarios 1, 2, and 3, respectively

A per capita discount was calculated to account for the lower economies of scale in poorer regions of Brazil, as illustrated in Eq. (4).

[2] https://paineis.mds.gov.br/public/extensions/observatorio-do-cadastro-unico/index.html

[3] https://aplicacoes.cidadania.gov.br/vis/data3/data-explorer.php

$$\text{Discount share to Non Beneficiaries}\left(\frac{\text{BRL}}{\text{per capita}}\right) = \frac{\text{Discount Scenarios}}{\text{Total population} - \text{Beneficiaries from Scenarios}} \quad (4)$$

3.3. Affordability ratios

The percentage of WSS expenditure relative to household average income or total expenditure is one of the most commonly used affordability ratios. A comprehensive literature review of 79 water affordability studies found that 40.6 % of these studies used the water bill as the numerator to calculate the amount spent by families, while 65.5 % used income as the denominator (Fagundes et al., 2023). As noted in prior research, updated census data is ideal for determining income if the methodology accounts for seasonal and informal income sources where relevant. In the absence of census data, specific income or expenditure surveys can serve as practical alternatives, particularly in low-income countries. Numerators may also include demand estimates derived from mathematical models (García-Valiñas et al., 2010; Sebri, 2015) or average consumption and tariff data from national reports and utility records.

According to (L. Andres et al., 2020), measuring affordability requires defining and incorporating the cost of a minimum basket of water, sanitation, and hygiene (WASH) services. This study assumes that, despite the limitation of available data, connected households receive an average quality of service. The affordability burden of WSS bills is calculated across four distinct income benchmarks: the state average wage, the poverty line (half of the national minimum wage), 200 % of the poverty line, and 60 % of the state average wage. The inclusion of the latter two benchmarks helps identify potential affordability challenges among families near the poverty line who are excluded from the benefits of the new law, as highlighted in previous studies (Waddams and Deller, 2015), given Brazil's pronounced income inequality. Also, in the indicators AR1 and AR4, in order to calculate the potential impact on residential connections that do not benefit from the law, the WSS (or WS) bill after counterweighting the discount fully with cross-subsidization was used, as described in item 3.4.

The average salary was derived using the state-level average wage from the Brazilian Households Survey 2024.[4] Since this average wage accounts for individuals aged 14 years and older, family income was estimated by multiplying the average salary by the national employment rate, the national proportion of individuals 14+, and the average household size in each city (all from the 2022 Census). However, due to the incomplete reporting of the 2022 Census, employment rates and salaries at the city level could not be incorporated into the analysis. It is important to emphasize that affordability analyses should prioritize the use of local data, when available, rather than relying on national information. The Affordability Ratios (AR) are expressed by Eq. (5) to 8.

$$AR1(\%) = 100 * \frac{WSS\ regular\ bill\ t1}{\frac{Hab}{HH} * Employment\ Rate * people\ over\ 14 * Average\ Wage} \quad (5)$$

$$AR2(\%) = 100 * \frac{WSS\ bill\ t1}{\frac{Hab}{HH} * \frac{1}{2} Minimum\ Wage} \quad (6)$$

$$AR3(\%) = 100 * \frac{WSS\ bill\ t1}{\frac{Hab}{HH} * Minimum\ Wage} \quad (7)$$

$$AR4(\%) = 100 * \frac{WSS\ regular\ bill\ t1}{\frac{Hab}{HH} * Employment\ Rate * people\ over\ 14 * 60\% * Average\ Wage} \quad (8)$$

where:

Hab/HH: Inhabitants per Household. Source: IBGE, 2023.[5] Employment Rate: National employment rate for individuals aged 14+ (45.56 %). People over 14: National proportion of individuals aged 14+ (80.2 %). Source: PNADC, 2023.[6] Average Wage: State average wage for individuals aged 14+. Source: PNAD, 2024.

The affordability ratios were calculated for the three previously described scenarios, as well as for a status quo scenario in which no tariff discounts are applied. For the status quo, it was assumed that families do not access the social tariffs applied by several utilities, as only a limited percentage of CADÚnico beneficiaries currently benefit from state-owned utility discounts (Fagundes et al., 2025).

Many international organizations and governments have proposed thresholds to define affordable WSS services. These thresholds include 3 % to 5 % of household income suggested by the World Bank, 5 % by the Asian Development Bank, 2.5 % by the United States Environmental Protection Agency, and 3 % by the OECD. A literature review revealed that 90 % of studies using affordability thresholds employed percentages ranging between 2 % and 5 % (Fagundes et al., 2023). For this study, thresholds of 5 % for combined WSS services and 3 % for water supply alone were adopted to determine whether services are affordable.

3.4. Tariff adjustment – cross-subsidization

Although the law mentions the creation of a National Fund to support necessary subsidies, it also incentivizes utilities to implement cross-subsidization, a common practice among Brazilian utilities. Given that many cities in Brazil rely on local providers and serve large populations in poverty, this study examines whether cross-subsidization alone could suffice to ensure affordability for customers who do not receive discounts. To analyze this, it was assumed that utilities must have the same revenue after law implementation. Considering that Revenue $_{t0}$ = Water tariff$_{t0}$ * total customers (beneficiaries + non beneficiaries), and Revenue $_{t1}$ = (Water tariff$_{t1}$ * Non beneficiaries) + (50 %Water Tariff$_{t1}$ *Beneficiaries). Eq. (9) shows the new average bill calculation.

$$Water\ regular\ bill\ t1(BRL) = \frac{WSS\ average\ bill\ t0 * (Beneficiaries + Non\ Beneficiaries)}{(0.5 * Beneficiaries) + Non\ Beneficiaries} \quad (9)$$

It is important to note that this analysis was limited to Scenarios 1 and 2 and assumed the proportion of rural beneficiaries with WS or WSS services as detailed in Section 3.1. Scenario 3, on the other hand, includes all potential beneficiaries, many of whom are not currently

[4] https://www.ibge.gov.br/estatisticas/sociais/trabalho/9173-pesquisa-nacional-por-amostra-de-domicilios-continua-trimestral.html?t=resultados

[5] Available at https://www.ibge.gov.br/estatisticas/sociais/trabalho/22827-censo-demografico-2022.html?edicao=37225&t=resultados.

[6] Available at https://sidra.ibge.gov.br/home/pnadcm

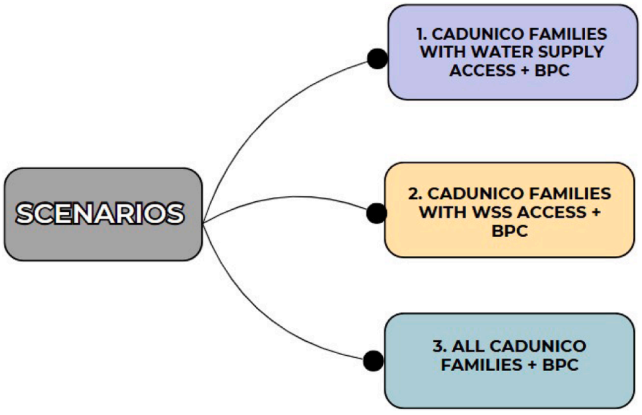

Fig. 3. Scenarios based on the service access.

connected to water or wastewater services. As such, they would not yet be eligible to receive tariff discounts.

4. Results and discussion

4.1. Scenarios adopted and potential beneficiaries

According to CADUnico, as shown in Fig. 4, up to 52.3 % of the population within the state earn half of the minimum wage or less per month and are registered in the national system. It is important to mention that not all poor populations are registered in the system, so the number may be higher than this - although not much more since the system is robust and well established in the country. Taking this information into account, cross-subsidization may not be the miracle answer for the affordability problem as the national government thought when creating Law No 14,898, 2024.

The total number of potential beneficiary families in Brazil is 24,188,522, of which only 3.9 % are represented by BPC beneficiary families. For the purpose of this study, we assumed that each family lives in a separate household with a private water connection. This assumption, while practical, is not entirely accurate. In reality, many low-income individuals, particularly in state capitals, live in collective housing arrangements. Additionally, since BPC data from the Ministry of Social Development count beneficiaries as individuals rather than households, this number was divided by the average household size per city. Taking these considerations into account, the findings presented herein represent a conservative scenario for utility providers.

Among the 23,533,407 poor families registered in CADUnico, 78.5 % reside in urban areas, and 89.3 % have access to some form of water supply. However, only 48.5 % have access to both a water supply and a sanitation network or drainage system. It is worth noting that this figure likely overestimates access to sanitation services due to limitations in the system's data and does not mean those families are utilities' customers. It was found that in 389 municipalities, the number of potential beneficiaries with access to water supply exceeded the number of existing residential connections, and in 128 municipalities for beneficiaries with WSS services. Although these cases represent only 7.2 % and 2.3 %, respectively, of the 5,390 municipalities included in this study, Fig. 4 shows that states in the northern region of the country face significantly higher poverty levels. This reality poses additional challenges for implementing the law solely among existing utility customers, as discussed further. Based on the scenarios considered in this study, the main findings are illustrated in Fig. 5.

The national government estimates that 9 million households would benefit from WSS social tariffs.[7] However, as shown in Fig. 5, the total number of potential beneficiaries identified in this study is significantly higher, even when accounting for the WSS access rate, despite some limitations in the data. For example, for Scenario 2, potential beneficiaries represent high proportion of utilities' customers: Bahia (45.6 %), Ceará (50.2 %), Maranhão (69.4 %), Paraíba (43.1 %), Pernambuco (50.4 %), and Piauí (83.4 %), which brings into question the sustainability of relying on cross-subsidization.

4.2. Discount

The total discount that all beneficiaries would receive was calculated on a per-city basis for each scenario. However, for clarity and comparability, the results are presented here at the country and state levels. It is crucial to note that, for Scenarios 1 and 2, it was assumed that all urban and partially rural beneficiaries are already utility customers. Under these conditions, utilities would not experience increased costs due to new connections but would instead face a direct economic loss as a result of providing discounts. In addition, Scenario 3 considers all potential beneficiaries as if they were existing customers, only for the purpose of total discount calculation. Fig. 5 illustrates the estimated monthly discount amounts across Brazil for Scenarios 1 to 3.

Table 1 shows the annual economic 'loss' utilities would face in order to apply the mandatory discounts, including the water consumption variation scenarios.

As shown in Table 1, the annual economic loss could reach up to 2.5 billion USD if all beneficiaries from CADUnico and BPC in Scenario 3 were customers eligible to receive the discounts. Although a more realistic perspective would consider the additional revenue generated by potential new customers, expanding the network to certain areas would simultaneously increase costs for utilities. Although Scenario 2 has fewer potential beneficiaries than Scenario 1, the discount in Scenario 1 is lower because it accounted just for water tariff.

These scenarios represent overestimated conditions, as the data on WSS access may overestimate the actual access of poorer families to these services, especially for sanitation services. This overestimation is likely due to factors such as the presence existence of collective social housing, which often relies on shared or collective connections, the classification of sanitation and drainage as a single service type, and, as explained earlier, the use of coverage rate rather than actual service provision reported on the national SNIS platform. Furthermore, the assumption that all potential beneficiaries are current utility customers is not entirely accurate. Figs. 6, 7, 8, 9 provide the results in maps for the country.

As shown in the previous figures, each state faces unique challenges in implementing the law within its jurisdiction. While the states of São Paulo and Rio de Janeiro account for the largest total surcharge, the scenario changes when considering the population sizes within these states. Figs. 10, 11, 12, 13 illustrate the monthly discount that each non-beneficiary (each person) would need to bear if utilities were to implement the law solely through cross-subsidization.

The law refers to a national fund to support the necessary subsidies. The details regarding its operation or funding sources are being discussed in the country at the time of writing. The law clearly prioritizes cross-subsidization among utility customers. We note in this paper the pitfalls of such an approach, not only due to the unfair burden it places on other customers but also because many utilities lack the economies of scale required to depend entirely on such a strategy. In Brazil, state-owned companies may facilitate cross-subsidization among cities within a state, but there remain approximately 1,340 local providers outside this framework. Even state-owned companies might face significant challenges implementing cross-subsidization, particularly in states with limited financial resources, as observed in Amazonas, Ceará, and Rio de Janeiro. To illustrate the issue, Table 2 shows the proportion of annual revenue of each state-owned provider each Scenario would take to implement the law through cross-subsidy. The coverage rate for each type of service is displayed to understand the reason some states

[7] https://www.youtube.com/watch?v=tivDt_Arj3I

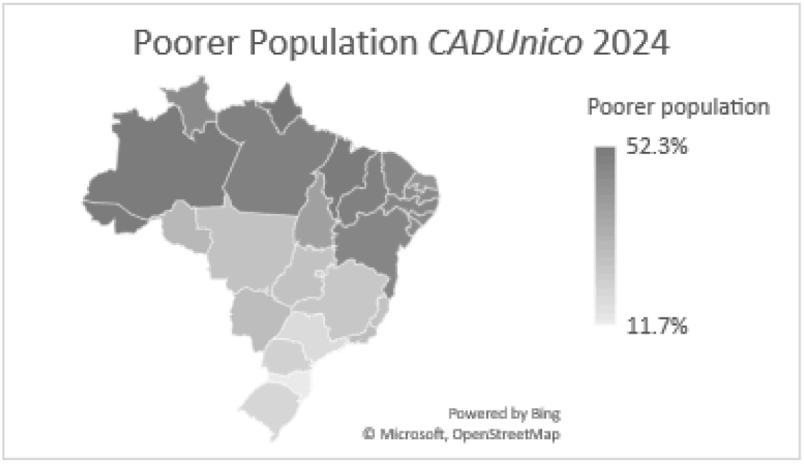

Fig. 4. Poorer Population in Brazil.

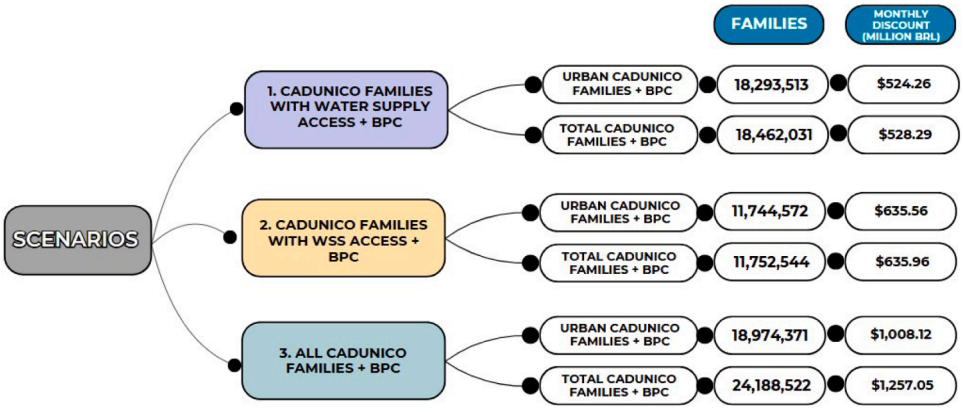

Fig. 5. Total Monthly Discount in Brazil.

Table 1
Annual Economic 'Loss' in Brazil in USD.

Annual Economic 'Loss' in Brazil (million USD)						
Scenarios	Average Water Consumption		20 % Increase in Water Consumption		20 % Decrease in Water Consumption	
	Urban Families	Total Families	Urban Families	Total Families	Urban Families	Total Families
Scenario 1	$1,132.41	$1,141.11	$1,297.86	$1,307.85	$1,016.70	$1,024.44
Scenario 2	$1,372.80	$1,373.67	$1,586.34	$1,587.35	$1,235.44	$1,236.22
Scenario 3	$2,177.53	$2,715.22	$2,468.08	$3,077.51	$2,019.20	$2,515.06

Exchange rate used in this paper dates from 05/11/2025. 1 BRL = 0.18 USD.

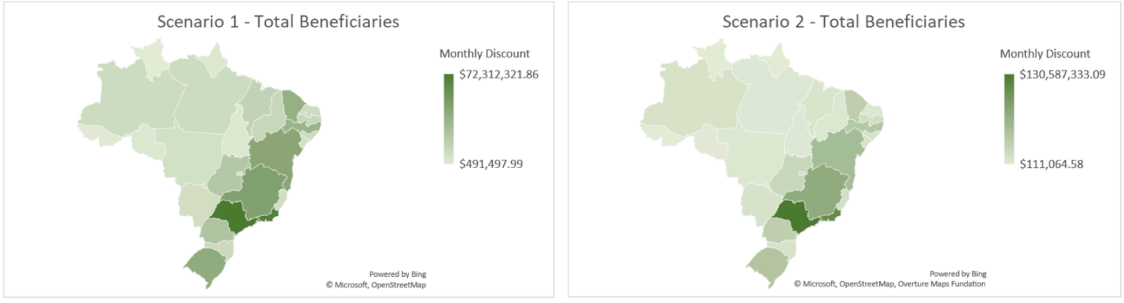

Fig. 6. Total Monthly Discount for Total Beneficiaries from Scenarios 1 and 2.

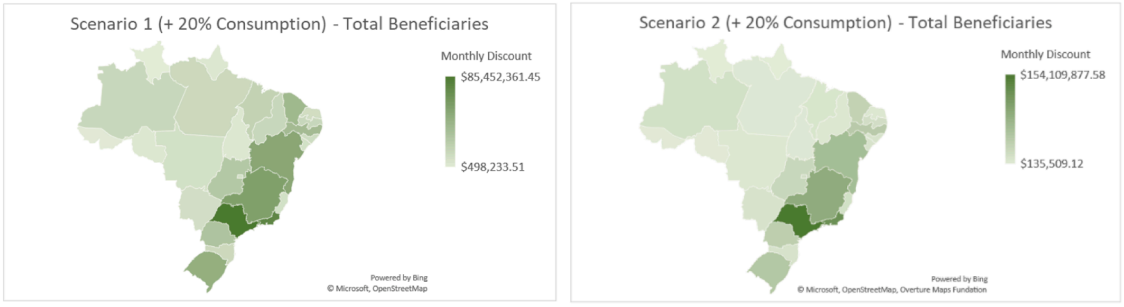

Fig. 7. Total Monthly Discount for Total Beneficiaries from Scenarios 1 and 2, for a 20 % increase in water consumption.

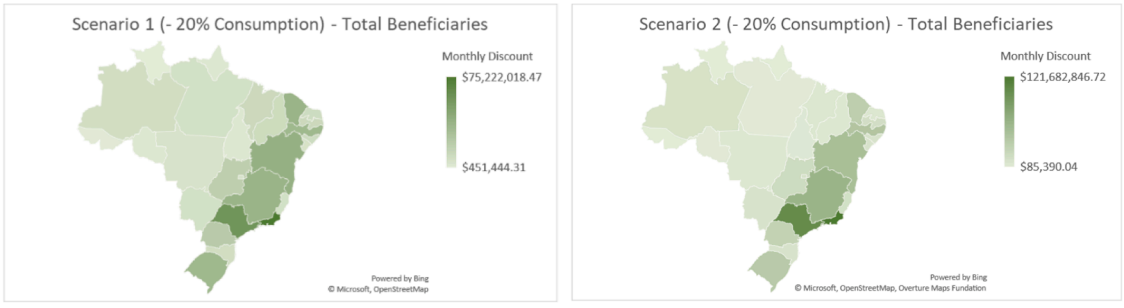

Fig. 8. Total Monthly Discount for Total Beneficiaries from Scenarios 1 and 2, for a 20 % decrease in water consumption.

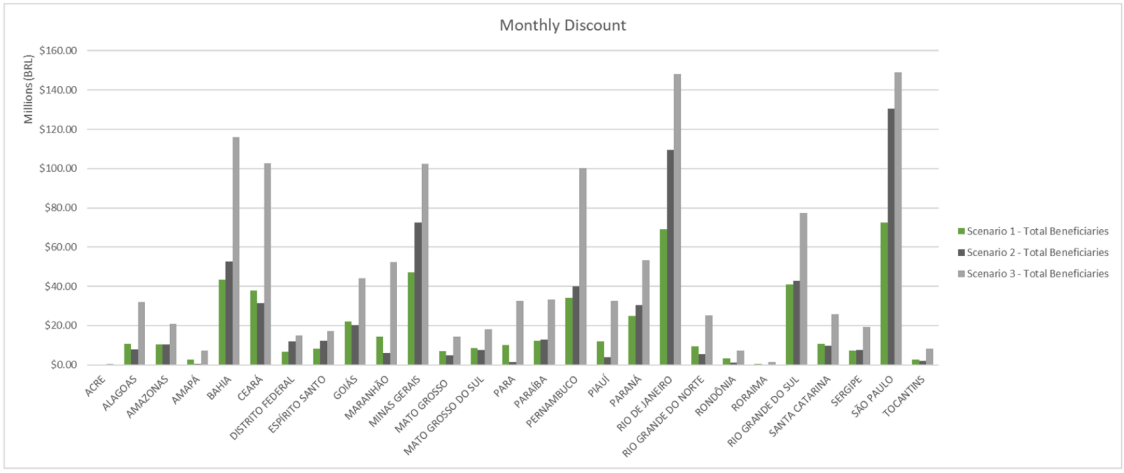

Fig. 9. Monthly Discount per state.

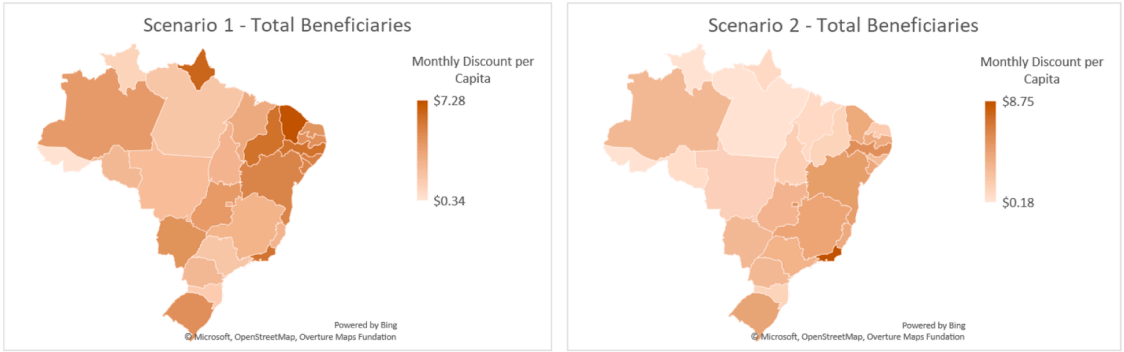

Fig. 10. Monthly discount shared to Non-Beneficiaries, Scenarios 1 and 2.

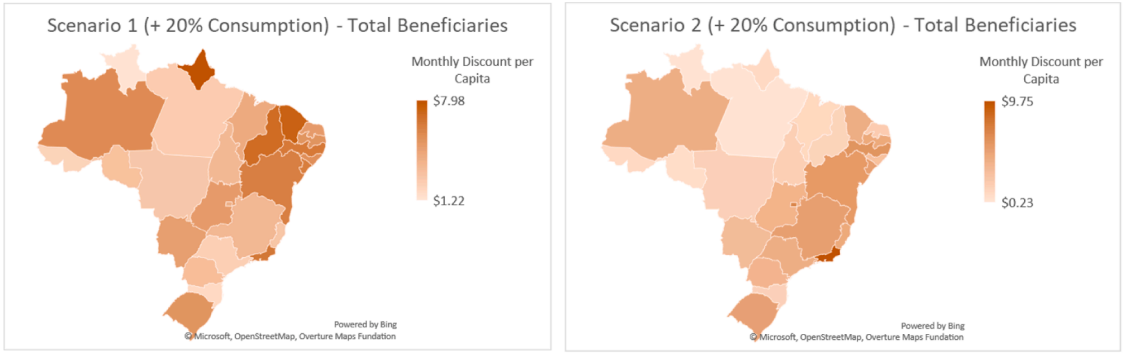

Fig. 11. Monthly discount shared to Non-Beneficiaries, Scenarios 1 and 2, for a 20 % increase in water consumption.

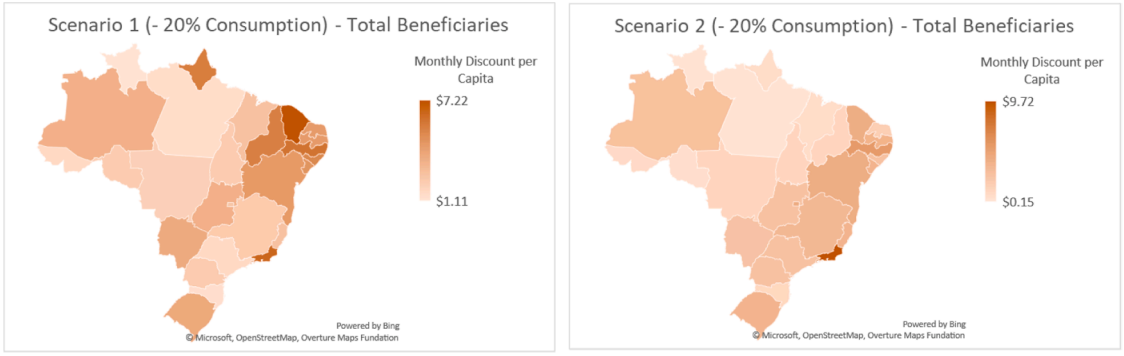

Fig. 12. Monthly discount shared to Non-Beneficiaries, Scenario 1 and 2, for a 20 % decrease in water consumption.

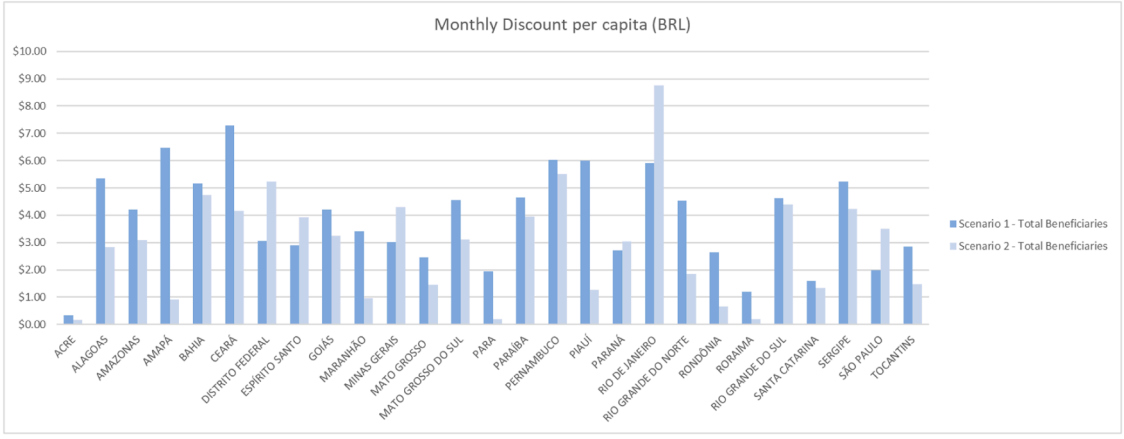

Fig. 13. Monthly discount shared to Non-Beneficiaries.

present a lower impact for Scenario 2.

As mentioned earlier, most state-owned companies already apply Social Tariffs, though with criteria and discount levels differ from those established by the new national law. Table 3 presents the potential annual economic 'loss' that utilities would incur if all households currently receiving social tariffs were granted the same discount defined by the new law, and for both WSS services. While the resulting financial impact would be lower than initially estimated, it would still amount to billions of USD under Scenario 3.

4.3. Affordability ratios

As explained in the methodology section, four Affordability Ratios were calculated before and after the application of the national law discounts, as results are presented in Table 4 and Fig. 14.

As shown in Table 4 and Fig. 14, the implementation of Law No 14,898 has the potential to enhance affordability for poorer populations. For instance, the number of cities with affordability challenges could decrease from 2,757 to 360 under Scenario 2. However, relying exclusively on cross-subsidization is likely to create affordability issues for non-beneficiaries. This effect is evident in Total Families under Scenario 1, where the number of cities facing affordability problems rises from 752 to 1569 for those earning the state average wage. For families earning one minimum salary per capita per month, this increase is also noticed, with the number of cities affected growing from 281 to 534.

When applying the sensitivity analysis (±20 % variation in water consumption), the results presented in Tables 5 and 6 reveal that quasi-poor households (those earning around 60 % of the state's average

Table 2
Impact of Discounts on Revenue of State-Owned Providers.

State	Region	Water Supply coverage rate	Sanitation services coverage rate	Impact of Discounts on Revenue of State-Owned Providers		
				Scenario 1	Scenario 2	Scenario 3
Acre	North	50.2 %	10.5 %	38.12 %	27.76 %	78.18 %
Alagoas	Northeast	30.9 %	1.8 %	18.43 %	13.09 %	40.97 %
Amazonas	North	32.9 %	6.8 %	51.63 %	2.53 %	61.81 %
Amapá	North	43.0 %	0.0 %	113.85 %	25.88 %	247.41 %
Bahia	Northeast	79.0 %	37.4 %	13.77 %	17.12 %	25.70 %
Ceará	Northeast	53.4 %	26.6 %	23.08 %	19.31 %	43.84 %
Distrito Federal	Central West	99.0 %	91.8 %	4.36 %	7.85 %	8.83 %
Espírito Santo	Southeast	80.0 %	50.7 %	7.92 %	12.06 %	14.27 %
Goiás	Central West	88.5 %	60.8 %	8.28 %	7.64 %	14.85 %
Maranhão	Northeast	46.6 %	13.1 %	37.05 %	15.44 %	82.10 %
Minas Gerais	Southeast	72.7 %	61.3 %	8.52 %	12.86 %	15.06 %
Mato Grosso do Sul	Central West	78.0 %	44.7 %	11.63 %	7.98 %	18.51 %
Pará	North	39.8 %	5.8 %	31.96 %	3.37 %	57.09 %
Paraíba	Northeast	76.1 %	32.5 %	14.51 %	15.61 %	28.43 %
Pernambuco	Northeast	83.4 %	23.2 %	22.94 %	26.72 %	51.08 %
Piauí	Northeast	48.5 %	6.8 %	22.69 %	7.56 %	43.87 %
Paraná	South	95.6 %	76.7 %	5.33 %	6.59 %	9.72 %
Rio de Janeiro	Southeast	86.8 %	43.0 %	10.72 %	18.29 %	21.85 %
Rio Grande do Norte	Northeast	80.7 %	24.1 %	14.25 %	8.29 %	26.11 %
Rondônia	North	34.9 %	3.1 %	24.31 %	7.07 %	43.62 %
Roraima	North	82.0 %	62.1 %	4.90 %	1.15 %	6.44 %
Rio Grande do Sul	South	82.2 %	16.1 %	11.68 %	10.82 %	18.53 %
Santa Catarina	South	86.8 %	23.7 %	5.52 %	5.35 %	11.38 %
Sergipe	Northeast	86.8 %	25.1 %	11.58 %	12.89 %	22.18 %
São Paulo	Southeast	96.5 %	89.6 %	4.48 %	7.98 %	8.58 %
Tocantins	North	88.4 %	40.6 %	5.17 %	3.81 %	10.68 %

Table 3
Economic 'Loss', considering current households under social WSS tariffs.

Annual Economic 'Loss' in Brazil (million USD)			
Scenarios	Average Water Consumption	20 % Increase on Water Consumption	20 % Decrease on Water Consumption
	Total Families	Total Families	Total Families
Scenario 1	$940.28	$1,077.67	$844.14
Scenario 2	$994.54	$1,149.24	$895.02
Scenario 3	$2,351.38	$2,665.12	$2,178.04

Table 4
Total Cities in Brazil with Affordability Ratios > 5 %.

Number of Cities with AR > 5 %					
Family Income	Before Law	Total Beneficiaries		Urban Beneficiaries	
		Scenario 1	Scenario 2	Scenario 1	Scenario 2
State Average Wage	752	1,569	1,121	1,557	1,120
Poorer Population	2757	427	360	427	360
200 % Poverty Line	281	534	397	526	397
60 % State Average Wage	3,437	3,655	3,566	3,653	3,565

wage) already face affordability challenges, as they are not eligible for most social assistance programs.

4.4. Tariff adjustment - cross-subsidization

Table 7 presents the median potential tariff adjustments required if the new law is exclusively financed through cross-subsidization, as indicated as the preferred approach in the legal framework. The results highlight significant disparities across states, particularly emphasizing the challenges faced by those in the northern region of Brazil. For the calculation, the cities where potential beneficiaries exceeded the current utilities' residential connections were excluded (389 for Scenario 1 and 128 for Scenario 3), since beneficiaries would represent 100 % of clients.

States in the North and Northeast generally show the most substantial tariff increases. These regions, known for higher poverty rates and lower coverage of WSS services, would face severe challenges in implementing the law without creating affordability issues for non-beneficiaries. Northern states such as Amapa, Roraima, Pará and Maranhão exhibit the highest average tariff adjustments, with potential increases of up to 47 % in Amapa, under Scenario 1 (Total Beneficiaries). In contrast, states in the South, such as Santa Catarina and Rio Grande do Sul, demonstrate much lower potential tariff increases, with adjustments as small as 2.5 % and 3.8 % in Scenario 2. States such as São Paulo, Rio de Janeiro, and Minas Gerais exhibit more moderate adjustments (11 %–25 % for Scenario 1), likely due to their larger economies and better-established infrastructure. Even so, the proposed increases in these populous states could create affordability concerns for some non-beneficiaries.

Another key observation regarding cross-subsidization is that while subnational regulators are unlikely to distribute the total discount exactly as modeled in this study (equally among all connections), our estimates may not deviate significantly from reality, due to the proportion of residential connections relative to the total (see Table 8) and the fact that industries have the option to rely on their own boreholes if tariffs become prohibitively high. This dynamic underscores the need for regulators to exercise caution in setting tariffs, ensuring they do not inadvertently drive away large customers who are crucial contributors to cross-subsidization efforts.

The use of cross-subsidies to finance social subsidies in utility services brings disadvantages highlighted since the 1990s, introducing inefficiencies by distorting pricing signals, reducing incentives for both efficient consumption and investment, and imposing hidden taxes on non-beneficiaries (Hausman, 1997). Implementing the law exclusively through cross-subsidization would disproportionately affect utilities in poorer states, where economies of scale along with high rates of poverty are insufficient to absorb such significant adjustments. For instance, in

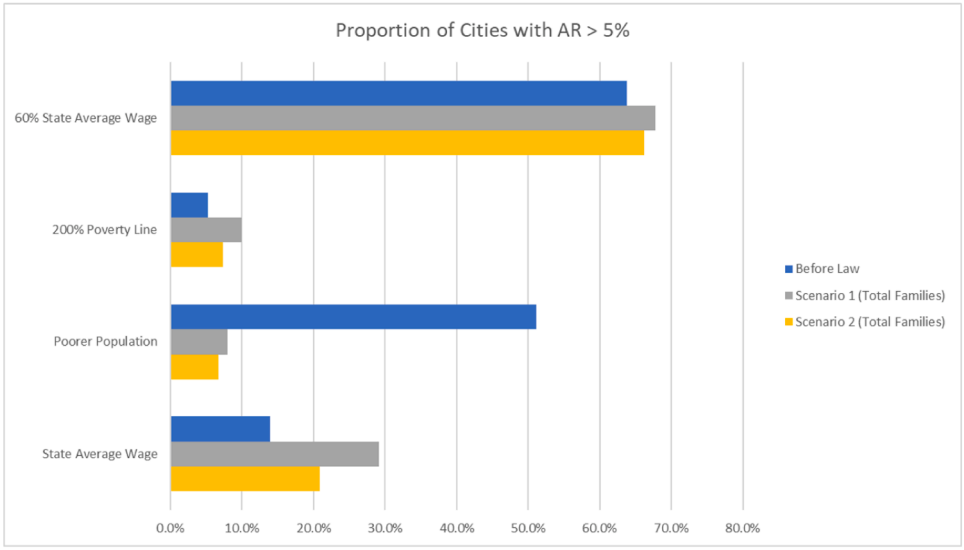

Fig. 14. Proportion of Cities in Brazil with Affordability issues.

Table 5
Total Cities in Brazil with Affordability Ratios > 5 % (+20 % water consumption).

Number of Cities with AR > 5 % (+20 % demand)					
Family Income	Before Law	Total Beneficiaries		Urban Beneficiaries	
		Scenario 1	Scenario 2	Scenario 1	Scenario 2
State Average Wage	1,529	2,403	1,946	2,391	1,946
Poorer Population	3,492	751	878	751	878
200 % Poverty Line	669	1,094	848	1,080	848
60 % State Average Wage	3,999	4,080	4,120	4,082	4,120

Table 6
Total Cities in Brazil with Affordability Ratios > 5 % (−20 % water consumption).

Number of Cities with AR > 5 % (−20 % demand)					
Family Income	Before Law	Total Beneficiaries		Urban Beneficiaries	
		Scenario 1	Scenario 2	Scenario 1	Scenario 2
State Average Wage	361	902	603	889	602
Poorer Population	1,968	175	120	175	120
200 % Poverty Line	94	234	145	225	144
60 % State Average Wage	2,761	3,234	2,996	3,235	2,995

Roraima, tariff increases of 46 % under Scenario 1, with 94.1 % of connections being residential, underscore the limited capacity of some utilities to manage the financial burden effectively.

While the intentions behind enacting Law No 14,898 were undoubtedly commendable, the lack of thorough socioeconomic studies is evident. A comprehensive affordability analysis should have been conducted before passing such a critical law. This analysis should have included social participation from key stakeholders, such as the Ministry of Social Development and subnational regulators, who are well-versed in existing tariff subsidies and their associated challenges. As highlighted by (Fagundes et al., 2025), WSS public policies must incorporate affordability assessments to improve decision-making and avoid excessive financial burdens on families while ensuring the sustainability and quality of WSS services. Chile, for example, operates a means-tested targeted subsidy program that directly compensates low-income households by covering a percentage of their WSS bills, even with higher administrative costs (Errázuriz and Gómez-Lobo, 2024).

One critical oversight in the legislation was the lack of consideration for WSS service coverage. Law No 14,898 will only benefit individuals already connected to utility services, leaving many without access entirely excluded. If the goal was to enhance economic access to WSS, it is essential to ensure physical access to WSS services first. Specific

Table 7
Potential Tariff Adjustment.

Potential Tariff Adjustment for Total Beneficiaries (Average)			
State	Region	Scenario 1	Scenario 2
Acre	North	43.8 %	6.1 %
Alagoas	Northeast	38.0 %	15.9 %
Amazonas	North	40.0 %	7.9 %
Amapá	North	47.0 %	8.3 %
Bahia	Northeast	29.3 %	13.6 %
Ceará	Northeast	36.9 %	8.9 %
Distrito Federal	Central West	11.5 %	10.2 %
Espírito Santo	Southeast	18.9 %	15.2 %
Goiás	Central West	17.9 %	4.5 %
Maranhão	Northeast	45.1 %	5.8 %
Minas Gerais	Southeast	16.0 %	12.8 %
Mato Grosso do Sul	Central West	18.8 %	6.6 %
Mato Grosso	Central West	16.8 %	2.2 %
Pará	North	41.9 %	4.8 %
Paraíba	Northeast	36.4 %	15.7 %
Pernambuco	Northeast	37.8 %	22.4 %
Piauí	Northeast	32.8 %	2.5 %
Paraná	South	13.0 %	5.5 %
Rio de Janeiro	Southeast	25.0 %	19.2 %
Rio Grande do Norte	Northeast	30.9 %	9.9 %
Rondônia	North	25.7 %	4.5 %
Roraima	North	46.0 %	6.5 %
Rio Grande do Sul	South	8.3 %	3.8 %
Santa Catarina	South	7.2 %	2.5 %
Sergipe	Northeast	28.2 %	10.9 %
São Paulo	Southeast	11.0 %	9.5 %
Tocantins	North	25.7 %	3.5 %
BRASIL		21.0 %	9.2 %

Table 8
Proportion of Residential Connections in Brazil.

Proportion of Residential Connections			
State	Total Connections	Residential Connections	Proportion
Acre	123,116	120,115	97.6 %
Alagoas	728,433	665,216	91.3 %
Amazonas	1,413,611	1,245,166	88.1 %
Amapá	75,763	67,883	89.6 %
Bahia	4,303,222	3,967,156	92.2 %
Ceará	2,379,293	2,221,327	93.4 %
Distrito Federal	1,102,562	1,044,591	94.7 %
Espírito Santo	1,314,378	1,192,860	90.8 %
Goiás	2,745,008	2,461,602	89.7 %
Maranhão	1,092,191	936,520	85.7 %
Minas Gerais	7,728,206	6,842,448	88.5 %
Mato Grosso do Sul	980,064	910,480	92.9 %
Mato Grosso	1,392,198	1,214,466	87.2 %
Pará	742,334	611,083	82.3 %
Paraíba	1,133,990	1,032,003	91.0 %
Pernambuco	2,507,830	2,376,546	94.8 %
Piauí	894,136	787,265	88.0 %
Paraná	4,417,732	4,016,002	90.9 %
Rio de Janeiro	6,082,922	5,610,272	92.2 %
Rio Grande do Norte	927,594	871,469	93.9 %
Rondônia	300,352	236,042	78.6 %
Roraima	123,837	116,526	94.1 %
Rio Grande do Sul	4,942,533	4,343,060	87.9 %
Santa Catarina	2,838,935	2,521,929	88.8 %
Sergipe	785,114	659,412	84.0 %
São Paulo	18,350,564	16,701,330	91.0 %
Tocantins	599,757	560,773	93.5 %
BRASIL	70,025,675	63,333,542	90.4 %

programs aimed at expanding WSS networks in underserved areas should have been implemented alongside, or even before the legislation. Additionally, affordability assessments conducted by subnational regulators prior to the law's enactment could have helped optimize subsidy allocation by prioritizing regions with the most critical affordability challenges. Such analyses would have also highlighted the limitations of relying solely on cross-subsidization, demonstrating that this approach is not universally feasible, as previously highlighted by other studies (Cardenas and Whittington, 2019; Nauges and Whittington, 2017; Pinto and Marques, 2015b). Some Brazilian regulators, like ARSAE in Minas Gerais state and ARES-PCJ in Sao Paulo state, have already applied affordability thresholds in their regulatory impact assessments, although, it remains unclear what actions are taken when these thresholds are exceeded.

Furthermore, a targeted evaluation should have been conducted to determine whether the proposed limits and discounts under the law are genuinely affordable for families living below poverty and extreme poverty lines. This targeted approach would ensure that the law meets its intended purpose of improving access for the most vulnerable groups. Clear targets should also have been established to account for beneficiaries already connected to utility networks, those in surrounding areas, and the total number of excluded individuals. While subnational regulators will likely address these factors when adjusting tariffs to implement the law, the national government should have provided clear priorities to guide investments and allocate resources to the national fund effectively. Importantly, the fund must include provisions to cover connection costs and fees, as these often impose a much greater financial burden on families than consumption expenses. Studies have demonstrated that these upfront costs can be a significant barrier to accessing WSS services (L. Andres et al., 2020; OECD, 2009, 2020).

To mitigate the burden on non-beneficiaries resulting from cross-subsidization, the Brazilian government should operationalize the National Fund established by the current legislation. International experiences offer useful models: in Chile and Portugal, social water tariffs are fully funded through general taxation, ensuring broader equity (Errázuriz and Gómez-Lobo, 2024; Pinto and Marques, 2015a). Alternatively, Brazil could adopt a hybrid model that combines cross-subsidization with National Fund contributions, guided by comprehensive affordability assessments. The country could also draw lessons from California's Family Electric Rate Assistance (FERA) program, designed to provide electricity bill discounts to moderate-income households that slightly exceed the eligibility thresholds of the California Alternate Rates for Energy (CARE) program. FERA specifically targets families with three or more members whose household incomes fall between 200 % and 250 % of the federal poverty guidelines. Eligible customers receive a reduction of approximately 18 % on their electricity bills, aiming to alleviate the energy cost burden for larger households with moderate income levels. Unlike CARE, which provides more substantial discounts, FERA offers a more limited benefit but still plays an important role in promoting energy affordability and reducing economic hardship among vulnerable, but not extremely low-income, consumers.[8]

The implementation of the law also introduces additional complexities regarding administrative complementary data. Under Brazil's General Data Protection Law (LGPD) and the regulations governing CADÚnico, state or municipal departments cannot directly share personal data from CADÚnico with WSS providers, as these providers often operate as private entities or public corporations under private law. To address this, regulatory entities must act as intermediaries, accessing CADÚnico data and providing only the necessary information to service providers for benefit allocation. However, this responsibility will fall on subnational regulators, many of which lack the capacity or resources to handle such tasks effectively, which may hinder the timely and accurate implementation of the law. Different countries have faced the same issue when trying to implement social programs based on means-tested approaches, such as Chile, United States, and Portugal.

5. Conclusions

The enactment of Law No 14,898 of 2024 demonstrates an effort to address water affordability for vulnerable populations in Brazil. By mandating discounts for low-income households registered in CADÚnico and BPC, the law sets a critical precedent for prioritizing social equity in public utilities. However, the findings of this study reveal significant challenges in its implementation, particularly the reliance on cross-subsidization as the primary funding mechanism. While cross-subsidization can redistribute financial burdens, its effectiveness is limited by regional disparities, with economically weaker states, such as the ones in the North and Northeast, facing disproportionate financial strain. These regions, already grappling with high poverty rates and low WSS coverage, would see tariff increases as high as 46 %, creating new affordability issues for non-beneficiary households.

The study highlights several gaps in the law's design and implementation strategy. First, the lack of a comprehensive affordability analysis prior to its enactment has led to unintended consequences, such as tariff increases for households near the poverty line. These increases could reduce water access for families who, while not officially classified as poor, struggle to afford essential services. Second, the exclusion of unconnected populations from the benefits of the law further exacerbates inequalities, as only households with existing utility connections are eligible for discounts. Expanding WSS infrastructure to include these populations should have been a foundational component of the law's rollout, especially considering the creation of the National Fund for Water Access.

To address these shortcomings, policymakers must adopt a multi-pronged approach. This includes conducting detailed affordability assessments to identify critical regions and vulnerable families, prioritizing subsidy allocations based on need, and exploring alternative

[8] https://www.cpuc.ca.gov/industries-and-topics/electrical-energy/electric-costs/care-fera-program

funding mechanisms, such as a national subsidy fund or federal support for states with limited resources. Additionally, the law's focus on cross-subsidization alone is unsustainable in regions with limited economies of scale or high poverty rates.

Moreover, this study emphasizes the importance of setting clear, measurable targets for beneficiary inclusion. These targets should account for connected households, those in areas easier to connect, and populations totally excluded from WSS services. Integrating these targets with national development goals, such as achieving universal WSS coverage by 2033, will require coordination between federal and subnational entities, as well as significant investment in infrastructure expansion.

In conclusion, while Law No 14,898 represents a vital step toward achieving greater equity in water affordability, its success will depend on addressing the financial, operational, and structural challenges outlined in this study. By incorporating robust affordability analyses, expanding WSS coverage, and strengthening regulatory frameworks, Brazil can ensure that this ambitious policy fulfills its potential.

CRediT authorship contribution statement

Thalita Salgado Fagundes: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Rui Cunha Marques:** Writing – review & editing, Validation, Supervision, Conceptualization. **Diogo Filipe da Cunha Ferreira:** Writing – review & editing, Supervision. **Tadeu Fabricio Malheiros:** 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.

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Data availability

No data was used for the research described in the article.

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