



Optimizing Water Sustainability: Revealing Cost Recovery Strategies in the Canary Islands (Spain). Stochastic Frontier Model

Juan C. Santamarta¹ · Anastasia Hernández-Alemán² ·
Noelia Cruz-Pérez¹ · Isabel Gamallo-Paz¹ · Jesica Rodríguez-Martín¹ ·
Ignacio de Martín-Pinillos Castellanos³ · Alejandro García-Gil⁴

Received: 27 September 2023 / Accepted: 8 February 2024
© The Author(s) 2024

Abstract

Article 9 of the Water Framework Directive (WFD) introduces cost recovery as an instrument aligned with the ‘polluter pays’ principle, aiming to contribute to the overall well-being of water bodies. In this regard, this research focuses on application of the cost recovery method in the context of the Canary Islands (Spain). The study provides a comprehensive description and analysis of the methodology established for the second cycle of planning (2015–2021) in the Canary Islands, offering a comparative assessment of results for each island. We employ a Stochastic Frontier Model, which allows us to assess the efficiency of different water production techniques. The results should be of great interest to public decision makers in the field of water management to minimize cost, allocate resources efficiently or review water tariffs. The findings underscore substantial variations in cost recovery across islands, emphasizing the need for enhanced water infrastructure methods and data acquisition. Future research needs to extend the years on cost recovery to incorporate economies of scale and type of ownership.

Highlights

- Identifying water uses and water services is key to calculating cost recovery.
- Only the financial costs are recovered on all the islands, in varying proportions.
- Quantifying non-financial recovery using indirect methods has been challenging.
- Water services require a cost-recovery mechanism for income classification.

Keywords River Basin Management Plan · Water Pricing · Water Management Efficiency · Economic Instruments

1 Introduction

The demand for ample quantities of high-quality water for various purposes is consistently increasing. For this reason, integrated management of water resources that considers the following aspects is required: population, economic development, water pollution, uncertainties in the face of climate change, resource availability, environmental concerns and sustainable development (Santamarta et al. 2022a, b). Within Europe, the Water Framework Directive (WFD) (EU 2000) serves as the overarching legislation encompassing all pertinent water management domains. The WFD goal is to attain a favourable status for water bodies, impacting their quality not only in terms of the advancement of aquatic ecosystems but also concerning water for human consumption and its utilization in diverse economic activities (Gallego-Ayala and Gómez-Limón 2009). Hence, as stipulated in Article 9 of the WFD, the principle of cost recovery for water-related services must be considered, including environmental and resource-related services, in accordance with the ‘Polluter Pays’ principle and a pricing policy that encourages efficient use of water resources by all users (Hughes and Malmqvist 2005). Water pricing is contemplated in the WFD with a dual role: a) as an incentive for efficient use; and b) as an instrument for cost recovery, clearly establishing that all member states must develop and implement water pricing policies that enable the recovery of the cost of water in all its dimensions, i.e., financial, environmental and resource costs (Tsitsifli et al. 2017).

However, the lack of specificity in the directive allows each country to develop its own regulations. Taking advantage of the generality of the WFD complicates decision making and transparency (Galioto et al. 2013). For this reason, according to Pellegrini et al. (2023), the WFD would benefit from having a greater variety of tools to address local specificities from various perspectives, as well as considering quotas, subsidies, and stakeholder participation as key elements of the process.

Focusing on the information about what constitutes a water service, it is any activity developed by an agent for the benefit of a user (domestic, industrial, agricultural and/or public) in relation to water resources (Mylopoulos and Fafoutis 2012). These services are subject to recovery through tariffs and charges, or as self-service payments. They are of two types: i) abstraction, impoundment, storage, treatment and distribution of surface water and groundwater; and ii) collection and treatment of discharged water. Depending on their nature within the water cycle, they can be either upstream services, where one agent makes water available to another who, not being the final consumer, will again offer another service; or downstream services, where the agents make water available to the final user (Fig. 1).

The financial costs of water services must be estimated through information from the agent providing the service or the financing agent (Alamanos et al. 2020). Environmental costs are the economic cost of the actions needed to minimize the environmental damage associated exclusively with the provision of water services (Cortignani et al. 2018). They are conceived as a penalty rate for pollution associated with the provision of water services. These are the costs of the measures that correct and/or avoid deterioration in water bodies due to the provision of a service (Kanakoudis et al. 2012). Moreover, the Program of Measures is the instrument that coordinates and integrates the measures necessary to achieve the environmental objectives set by the WFD (Carvalho et al. 2019). Finally, resource cost is considered the cost of scarcity, understood as the cost of the opportunities renounced when a scarce resource is allocated to one use instead of

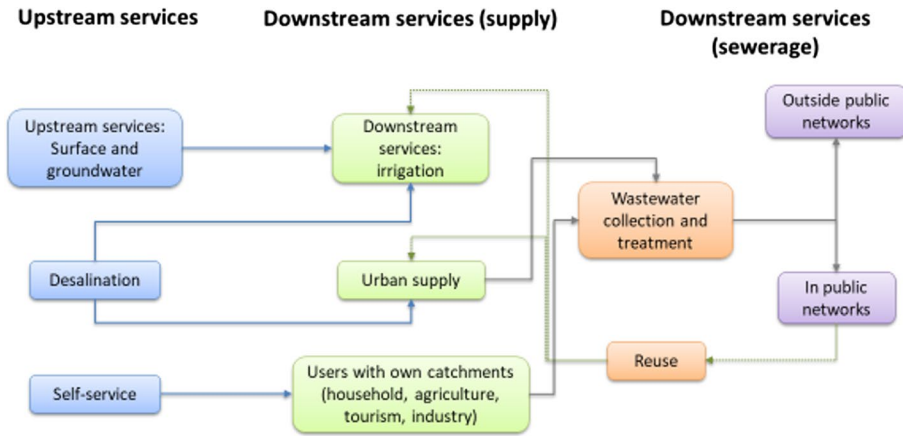


Fig. 1 Water services from catchment to end-user and reuse

another (Albiac et al. 2020); it also relates to lost revenues due to the alternative water uses that were not chosen (Turner et al. 2019).

The Canary Islands form a Spanish archipelago and represent an outermost European region that encounters distinct challenges in water management compared to continental areas (Fig. 2). The climate is subtropical, and temperatures are strongly linked to the effect of the trade winds on these islands. The relationship of the Canary Islands with water is a very close one, where the exploitation of groundwater resources, through horizontal water

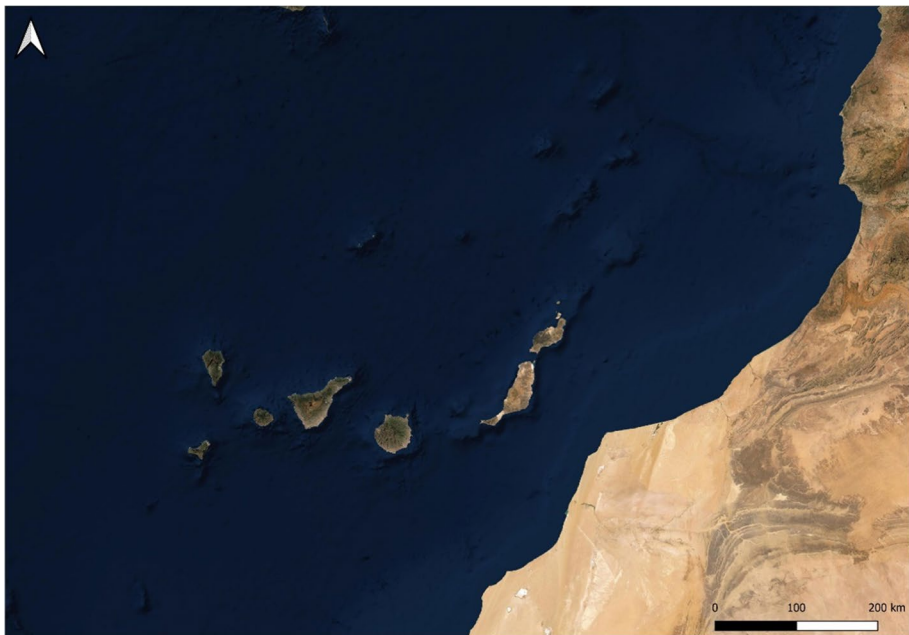


Fig. 2 Canary Islands (Spain), where each of the seven islands has its own River Basin Management Plan

mines (galleries) and coastal wells, stands out (Santamarta et al. 2014). Of lesser importance is the contribution of surface water, since precipitation is of the order of 350 mm per year (González-Morales and Ramón-Ojeda 2019). Seawater desalination is a solution that is gaining more and more ground in the archipelago (Gómez-Gotor et al. 2018), due to high population and tourism, as well as agriculture, which has the highest water demand of all the sectors in the Canary Islands (Díaz et al. 2011).

One of the main peculiarities of the Canary Islands is that most of the groundwater is privately owned (Custodio et al. 2016). Private investment to finance drilling works that illuminate groundwater (galleries and wells) was translated into shares. The shareholders, in turn, are grouped into Water Communities or Irrigation Communities, and they can use their water in any way they wish – use their own water, sell the shares or the water to third parties and/or cede the temporary management of the rights of the shares to a third party (Macías Hernández 2009).

According to Khemlani et al. (2021), the Canary Islands face a number of cross-cutting and specific challenges affecting water management. Among the cross-cutting challenges are the following: i) the orography of the terrain (Coello-Bravo et al. 2020), which poses a challenge in terms of access to drinking water in many localities; ii) the increase in the local population; iii) the ever-growing foreign and national tourism (Gundelfinger-Casar and Coto-Millán 2018); and iv) climate change, which is the new paradigm from which the water challenge in the Canary Islands must be approached (Santamarta et al. 2021). Areas of specific interest include droughts, the decrease in groundwater resources due to exploitation of the aquifer since 1920 (Custodio et al. 2016), the low quantity of surface water resources, and the increase in desalination in order to meet the high water demand of the Canary Islands (Schallenberg-Rodríguez et al. 2014).

However, the increase in desalination in the Canary Islands must be viewed in conjunction with the islands' energy consumption (Santamarta et al. 2022a, b). Desalination requires significant amounts of energy, and the Canary archipelago has a very low penetration of renewable energy in its electricity mix (Gobierno de Canarias 2022). As a result, the water cycle in the Canary Islands notably contributes to CO₂ emissions into the atmosphere (Cruz-Pérez et al. 2022). In addition, wastewater treatment and management also present important economic and environmental challenges, which have yet to be exploited in the Canary Islands (Ruiz-Rosa et al. 2016).

Another important challenge in the Canary Islands is the renovation of water supply pipes that generate high water losses in the Islands, with consequent loss of the resource (Santamarta et al. 2021). This will need to be alleviated in the near future to avoid water wastage and will require a large investment of public money. As mentioned earlier, the water resource in the Canary Islands comes from groundwater (a valuable resource that has sustained life in the Canary Islands) and desalination. Therefore, losing drinking water in potable water distribution networks means losing a millennia-old groundwater resource, as well as using significant amounts of energy and increasing emissions into the atmosphere to produce that water. This is in addition to the impact of brine on the marine ecosystem in the Canary Islands (Kress et al. 2020).

The stochastic frontier model allows us to assess the efficiency of different water production techniques. Dealing with the comparison of heterogeneous units is common to efficiency studies of water production, and for this reason, many studies have employed the frontier approach (Guerrini et al. 2018; Laureti et al. 2021; Molinos-Senante and Maziotis 2019). Through this model, we estimate probable water yields according to production technology, considering that there is a random variable based on variations found in historical data. This random variable

could be explained by the losses due to distribution networks. Considering the island context, we have the advantage of having water production data with different technologies.

The aim of this study is to analyze the cost recovery established by the River Basin Management Plans of the second cycle for the Canary Islands, and to analyze the results for each of the islands, in order to better understand the existent mechanisms that contribute to good status of the water bodies.

2 Methodology

To calculate cost recovery related to the water cycle, it is necessary to identify and describe water uses (upstream services, downstream supply services and downstream sewerage systems), and water services (defense against floods, environmental defense and water management in general). An estimation of the investment costs per year is made. In order to do so, it is necessary to calculate the Equivalent Annual Cost (EAC) (Wang et al. 2018), using the following equation:

$$EAC_{inv.} = \frac{(1 + r)^n - 1}{r \cdot (1 + r)^n} \cdot I \tag{1}$$

where r is the discount rate (as a decimal), n is the useful life (years) and I is the initial investment (at constant prices).

Consideration should be given to water service grants, investment, capital and accounting costs, as well as administrative, operating, and maintenance expenses. This information can be obtained from public and state agencies (Table 1). With this information, capital and exploitation costs can be estimated by compiling the data.

As mentioned before, environmental costs are the estimated cost of measures taken to reduce environmental impacts associated exclusively with water provision services. Internalized and outstanding environmental costs are obtained using this method. Outstanding costs are estimated by the EAC equation (Eq. 1) for the measures yet to be executed. Internalized costs are the maintenance and operation costs of the actions currently being executed; therefore, for these measures, costs must be deducted from their financial costs. The only actions considered for estimation are aimed at environmental correction of

Table 1 Classification of the sources of information by agencies

Agency	Source of information
Ministry for the Ecological Transition and the Demographic Challenge (MITECO)	State General Budget
Ministry of Finance and Public Administration	Provincial Councils
Hydrographic Confederations	MITECO'S Forecasting and budgeting
State-owned enterprises (SEIH and SEIASA)	Capital budgets and balance sheets from state-owned companies
Autonomous communities of Spain	Budget forecasts
Entities for water supply and sanitation	AEAS (Spanish Water and Wastewater Association)
Irrigation Communities	Surveys conducted by private companies
Self-service	MITECO

deterioration caused by the provision of water services linked to Article 2.38 of the WFD (EU 2000).

Resource costs are described from market instruments and how they allow improvement in economic conservation of the resource and environmental flows. They signify the cost of scarcity or the lost income from alternative water uses. In this study, they come into consideration during a river transfer or the production of water through desalination. For the case study, the only numerical value considered for cost recovery is that of desalination, as no river transfers are made in the islands. They must be considered as the production cost of the water sale price at the plant.

Water services must have a cost recovery instrument, which is necessary to characterize the provision of water services as an income. Table 2 sums up the main instruments for cost recovery considered for the Canary Islands.

The WFD methodology for cost recovery establishes that in order to calculate cost recovery, the costs must be compared with income obtained from users for the provision of the different services (EU 2000). The results are obtained for each agent from public and private entities.

The cost recovery rate is calculated by dividing annual income and the annualized cost for water services. This rate must be specified, at least for urban water supply and agricultural and industrial uses. Evaluation of the penalty for contamination and recovery of environmental costs must also be considered. The cost recovery methodology that has been implemented in the Canary Islands follows the structure shown in Fig. 3.

2.1 Econometric Analysis

The methodology used in this section refers to the principle of technical efficiency applied to cost recovery for water-related services. In this section, an analysis is made of the technical efficiency of water services, considering costs related to the production and distribution of water services. The objective is to obtain an estimate of technical inefficiency in the provision of water services, based on available data. The process of water production and distribution, as shown in Table 2, involves both public and private institutions. By estimating technical inefficiency, we are estimating the degree of efficiency/inefficiency of the institutions involved in the production and distribution of water services. However, we should be cautious in the interpretation of the results, due to the limited data available, so that we do not have a panel of data that would allow us to make a better assessment of the differences by islands. Using cross-sectional data, we are also unable to observe changes over time.

The model presented below considers the costs related to upstream water services (surface and groundwater) and desalination on the production side, and the costs of distribution services, such as downstream irrigation water distribution and urban supply on the distribution side. Based on these production and distribution factors, a stochastic frontier is configured for the cost function. The stochastic frontier model is motivated by the theoretical idea that no economic agent can exceed the ideal "frontier" and the deviations from this extreme represent individual inefficiencies (Belotti et al. 2012). The ideal "frontier" means the minimum expenditure required to produce a bundle of outputs, given the prices of the inputs used. Self-service is excluded from the model, as it is not quantitatively representative. Surface water comes from reservoirs, groundwater is abstracted through aquifers, and desalinated water is obtained from desalination facilities. The total costs of water services, which form the dependent variable, are composed of environmental costs, resource

Table 2 Cost recovery instrument by service and agent providing the service

Water service (definition article 2.38 WFD)	Details of the service	Agent providing the service	Cost recovery instrument
Extraction, impoundment, storage, treatment and distribution of surface water and groundwater	Extraction and supply of groundwater in high groundwater	Private individuals Island Council of El Hierro	Public price or rate for water supply
	Downstream irrigation water distribution	Insular Water Council of El Hierro	Rate for water supply
Collection and treatment of discharges to surface waters	Urban water supply (drinking water treatment and distribution)	Community of irrigators Municipalities	Rate for the provision of the Domestic Drinking Water Supply Service and Connections (Valverde) Water rate
	Self-service	Private individuals Private entities	
Collection and treatment of discharges to surface waters	Desalination	Island Council of El Hierro	Public price or rate for water supply
	Collection and treatment outside public networks	Insular Water Council of El Hierro Private individuals	
	Collection and treatment in public networks	Municipalities	Rate for the provision of sewage services (Valverde)
		Island Council of El Hierro	Sanitation fee (El Pinar) Sewerage rate

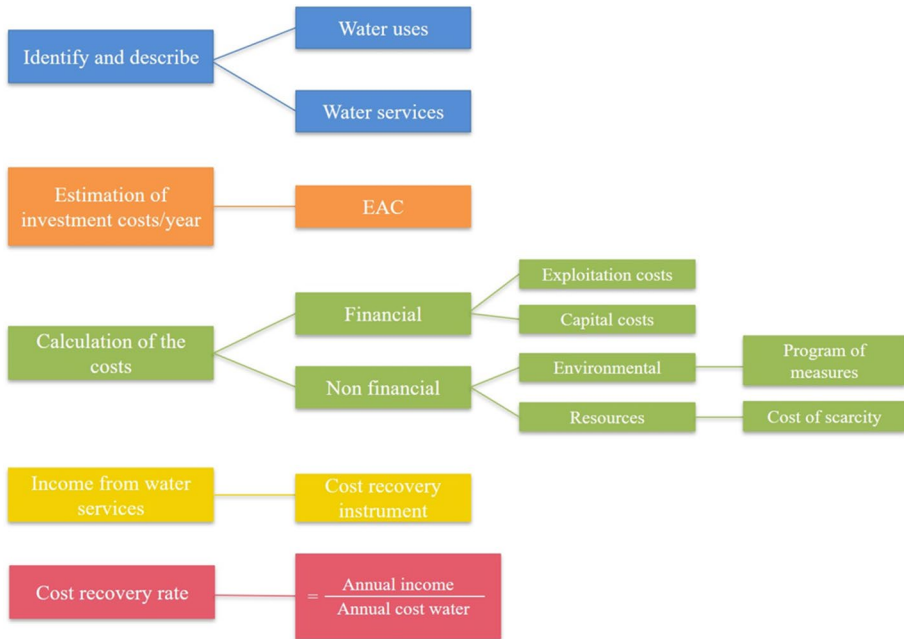


Fig. 3 Process followed in the calculation of cost recovery for the Canary Islands

costs and financial costs. Environmental costs are conceived as a penalty rate for polluting. Resource costs represent the scarcity of the resource or the opportunity cost of its use. Financial costs are the costs necessary to obtain the resource.

2.1.1 Stochastic Frontier Model

The main purpose of using a stochastic frontier model is to estimate the efficiency of cost recovery of water, considering the production and distribution of water services. The costs of water services are influenced by the technology employed and also by all the inputs necessary to carry out production and distribution. Stochastic frontier analysis is the most popular tool for efficiency analysis. It is a stochastic approximation method to determine production efficiency (Aigner et al. 1977; Battese and Coelli 1992; Belotti et al. 2012; Farrell 1957; Guerrini et al. 2018; Laureti et al. 2021; Molinos-Senante and Maziotis 2019). In our case, the objective is to estimate an optimal cost frontier. A deviation from the frontier reflects both inefficiencies and noise in the data. For this reason, two residual terms are considered in the model: one captures the error from unpredictable (random) disturbances; the other captures technical inefficiency.

The model is as follows:

$$CT_i = \alpha + X_i\beta + \varepsilon_i \quad (2)$$

$$\varepsilon_i = v_i - s\mu_i \quad (3)$$

Table 3 Values obtained from stochastic frontier model

Variables	Coefficient	Std. Err.	$p > t $	[95% Conf. Interval]
Upstream water services: surface	0.083	0.000	0.000	0.0817 0.0853
Upstream water services: ground	0.264	0.004	0.000	0.2559 0.2732
Urban water supply	0.393	0.013	0.000	0.3661 0.4208
Desalination	0.157	0.004	0.000	0.1486 0.1654
Downstream irrigation water distribution	0.083	0.009	0.000	0.0654 0.1018
constant	0.002	0.012	0.837	-0.0214 0.0264
v_i	-14.83	0.535	0.000	-15.879 -13.779
μ_i	-27.40	26,430.4	0.999	-51,831.02 51,776.34
σ_{v_i}	0.0006	0.0001		0.0003 0.0010
σ_{μ_i}	1.16e-06	0.1529		0
σ	3.63e-07	1.95e-07		-1.98e-08 7.46e-07
λ	0.0019	0.0153		-0.02807 0.03191
LR test ($\sigma_{\mu_i}=0$; $\chi^2=0$; prob > = $\chi^2=0.999$)				

Sign. codes: '**' 0.05

Table 4 Estimating technical inefficiency (Jondrow et al. 1982)

Variable	Mean	Std. Dev.	Min	Max
$E(s\mu \epsilon)$	0.00059	0.00092	2.87e-11	0.0021

Sign. codes: '**' 0.05

where CT_i is the vector of total costs; X_i are the outputs; $s=1$ for production functions; $s=-1$ for cost functions; ϵ_i is the stochastic disturbance term, where v_i is the random term containing the unpredictable disturbances or noise in the data, which is assumed to have a normal distribution and independent from μ_i ; μ_i is nonnegative disturbance, standing for technical inefficiency in the cost inefficiency of the cost function; α and β parameters are estimated where β represents the vector of technology parameters. The inefficiency term is assumed to be a half-normal distribution $[\mu_i \sim N^+(0, \sigma_\mu^2)]$. Each observation i represents each island in our case study. The function defines a minimum level of costs associated with the outputs (production and distribution) that correspond to water services. Two factors affect the efficient production term, and they have to do with the imbalance between marginal costs and marginal revenues. The second factor has to do with technical efficiency, which is analysed in this case. Technical efficiency is understood as the capacity to produce the service at minimum cost in financial, environmental and resource terms. The function defines a minimum cost limit. The difference between this theoretical benchmark and the actual benchmark is known as technical inefficiency. The model is estimated by maximum likelihood (ML).

From the results (Table 3 and 4), it can be seen that all the production and distribution factors considered are significant and have a positive impact on the generation of costs. This result is therefore in line with expectations. The factors with the highest impact on recovery costs are urban water supply (0.39), followed by groundwater services (0.26) and desalination (0.15); ϵ_i is positive, so there is no technical inefficiency problem, although the noise in the data is significant; v_i containing the unpredictable disturbances is significant

and somewhat high. The term μ_i , relating to technical inefficiency, is not significant. Technical inefficiency ranges from -0.02 to 0.03, the values being quite small and including zero in the confidence interval, as can be seen from the λ values in Table 3. More interesting, if the data allowed it, would be to compare technical efficiency by island and over time, which would require a panel of data. It is very likely that a panel of data would reduce the noise in the data, making it possible to establish a ranking of efficiency between islands (Schmidt and Sickles 1984).

In order to separate the error term of the stochastic frontier model into its two components (the inefficiency deviations and the stochastic deviations), Jondrow et al. (1982) proposed a method that allows estimation of the level of technical inefficiency for each observation in the sample, thus overcoming a disadvantage of the stochastic frontier model. The estimation of Jondrow et al. (1982) technical efficiency is based on calculation of the mean of the conditional distribution of the error term, which represents the technical inefficiency (μ_i), conditional on the composite error of each productive unit i (ε_i). Table 4 shows that the average technical inefficiency is 0.00059, with a standard deviation of 0.00092. This result is consistent with the non-significance of the term μ_i that we observe in Table 3.

3 Results and Discussion

The breakdown of cost recovery by cost type for each island, and for the second cycle of the River Basin Management Plan, is illustrated in Table 5. In general, at least part of the financial cost is recovered in all islands. Tenerife and Gran Canaria show the highest values for financial cost recovery. This could be due to the fact that, as these two are the capitals of the two provinces of the Canary Islands, this is where most of the population is located and they have more tourism, which requires more water infrastructure development (Custodio et al. 2016).

In Tenerife, complete financial cost recovery for desalination and water reuse could compromise its development (CIATF 2018), as it is still necessary to invest in the improvement of these facilities to reach a good quality of water with the least impact to the environment (Dallavalle et al. 2021). El Hierro, La Gomera and La Palma show very low financial cost recovery, due to the fact that a low percentage of the demanded water is billed to users, and information from private services is not always up to date or available (CIALP 2018).

Lanzarote and Fuerteventura are highly dependent on desalination as a source for urban supply, due to the low availability of surface or groundwater resources (Gómez-Gotor et al.

Table 5 Classification of the costs in the islands

Island/Cost	Financial (M€)	Environmental (M€)	Resource (M€)	Total* (M€)
Gran Canaria (GC)	163.18	1.89	23.19	188.27
Fuerteventura (FV)	19.88	0.74	0.00	20.62
Lanzarote (LZ)	39.55	1.12	0.00	40.67
Tenerife (TF)	239.40	13.10	0.00	252.50
La Palma (LP)	11.92	0.58	0.03	12.53
La Gomera (LG)	6.21	0.93	0.00	7.14
El Hierro (EH)	5.13	0.00	0.45	5.58

Second cycle of the Canary Islands River Basin Management Plans

2018). The reason that recovery of financial costs is not that important is the high maintenance and operation costs of desalination plants. The costs associated with the utilization of desalination plants are partially offset through recuperation from other services, as is also the case on the island of Lampedusa (Palmeros Parada et al. 2023).

Table 5 and Fig. 4 show that financial cost recovery is much more important than non-financial cost recovery (environmental and resource costs). This is because they are calculated with economic information provided by state administration. Non-financial recovery is estimated through indirect methods and, in many cases, it is difficult to reach a numeric value.

Figure 4 shows that resource costs represent a very small portion of costs; they are difficult to compute, as they are estimated as the cost of scarcity. They have only been considered in Gran Canaria, La Palma and El Hierro. Gran Canaria presents the highest resource cost recovery among the islands, representing 98% of the resource costs calculated. Environmental cost recovery has been estimated from the measures taken to improve water services according to Article 2.38 of the WFD. In general, as seen in Table 5, it is minor compared to financial cost recovery. It can be deduced from the data that there is an investment to improve water services but not enough economic recovery from the instruments cited in Table 2.

Although calculating environmental costs may be challenging, it is necessary, especially in territories such as islands, which are more vulnerable to climate change (Hernandez et al. 2018) and to consider its effects on groundwater. This is due to the deterioration caused by the intrusion of seawater, a result of rising sea levels, decreased precipitation, and other projections that need to be included and that affect numerous island territories (Gohar et al. 2019).

In Table 5, it can be seen that Tenerife island recovers more environmental cost, meaning that the investments the island made to improve infrastructures for water services are

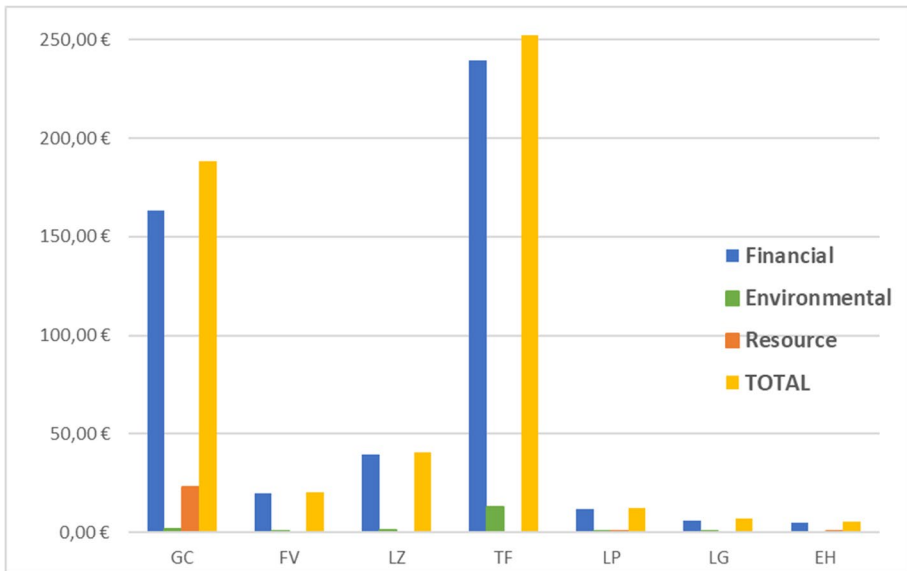


Fig. 4 Representation of the costs calculated for each of the Canary Islands. Source: second cycle of the Canary Islands River Basin Management Plans (Results are expressed in million Euros)

compensated with public and private rates. For its part, El Hierro island does not perceive any recovery from environmental costs (see Table 5) but it is expected that, for the third cycle of the River Basin Management Plan, the proposed measures (improving water infrastructure, diagnosing cost recovery by the services, controlling surface and groundwater extraction or improving wastewater management) will improve these results in the future (CIAEH 2018). It is expected that the next planning cycle (2022–2027) will show improved environmental costs, thanks to implementation of the measures proposed in the second cycle that are mainly based on reduction of losses in water networks and improvement in production and maintenance at desalination plants.

Cost recovery fluctuates significantly across islands and among different water services. Table 6 indicates the absence of available information on cost recovery beyond public networks, except for Tenerife island. This is due to the difficulty of obtaining information from private entities and individuals. As for self-service, it is difficult to estimate, as in most cases it is performed by private entities that do not provide information.

In general, upstream surface water services recover a small amount of money because of low surface water availability due to irregular distribution of precipitation (Sánchez-Benítez et al. 2017) and the elevated costs of creating infrastructure that will not provide much water and will not be amortized. In the case of Gran Canaria island, cost recovery for urban water supply is elevated. This is a representation of the efficiency in supply services and the efficient application of tariffs to users.

Desalination costs as a differentiated service were difficult to estimate, due to the low disaggregated information available, since most of the installed desalination capacity is managed by supply service concession companies or by municipalities that also directly provide the service (CIALG 2018). For this reason, part of the desalination costs has been included in the urban water supply. Upstream water services show a lower recovery (see Table 6), as they are mainly controlled by private entities, and the information was not available.

Fuerteventura island does not have any cost recovery related to upstream water services, as there is little information related to how exploitation of the resource is made (CIAFV 2018). The most important cost recovery comes from desalination (see Table 6), although it also accounts for most of the operation and maintenance costs. There is a strong need, in the case of this island, to improve control of losses in the water network system and to improve the mechanisms that control water production and supply. In the case of Lanzarote island, water supply comes from desalination, and costs for production and distribution are elevated, especially regarding energy consumption in the production process (CIALZ 2018). Table 6 shows that water reuse also represents a quite significant amount of cost recovery and is mainly used for agricultural purposes. There are no large volumes without invoicing on the island (CIALZ 2018).

Tenerife's River Basin Management Plan contains a very detailed analysis of cost recovery from all the water services and sources of information. Table 6 shows that highest cost recovery is due to groundwater upstream services, and urban water supply as groundwater infrastructure is well established (Custodio et al. 2016), meaning that less inversion is required in the water network. There is also an important cost recovery from desalination, as only the costs for operation and maintenance of the plant have been considered. The low-cost recovery for water reuse in Table 6 is due to investments that had been made to improve the water network infrastructure, in order to transport water from urban areas, where it is produced, to the agricultural fields, where it is mainly used (CIATF 2018).

On the island of La Palma, cost recovery for the services of water use, in general, are not very high; they represent about 47% for urban water supply and 51% for agricultural

Table 6 Cost recovery for each island and type of water service

	GC (M€)	FV (M€)	LZ (M€)	TF (M€)	LP (M€)	LG (M€)	EH (M€)
Upstream water services: Surface	0.69	0.00	0.00	0.90	0.06	0.79	1.35
Upstream water services: Groundwater	3.60	0.00	0.00	87.10	1.16	1.33	0.38
Downstream irrigation water distribution	34.80	0.12	0.00	0.00	4.46	1.85	0.00
Urban water supply	107.02	2.19	0.00	63.90	3.68	1.34	1.46
Self-service	0.00	0.00	0.00	0.00	0.00	0.00	0.05
Water reuse	8.75	0.21	1.19	9.20	0.00	0.10	2.13
Desalination	14.38	12.06	31.58	33.60	0.00	0.00	0.00
Collection and treatment outside public networks	0.00	0.00	0.00	8.50	0.00	0.00	0.00
Collection and treatment in public networks	19.03	6.04	7.90	49.30	3.16	1.73	0.21

Source: second cycle of the Canary Islands River Basin Management Plans

uses. There is a strong need, in this case, for impulse measures that improve cost recovery mechanisms. For La Gomera island, cost recovery is very low also, from downstream irrigation water distribution gathering in 1.85 M€. It constitutes a special case in terms of water management since, in general, it is not charged for most uses, which means that cost recovery is low (CIALG 2018). In this case, it is very important to at least improve financial cost recovery and establish a better system, in which the water consumed in both urban and agricultural services is billed.

In El Hierro island, the major cost recoveries are perceived to be from desalination and urban water supply. Cost recovery is higher for desalination than for upstream services, despite the fact that operation and maintenance costs can be due to the difference between water produced/bought and the water that is invoiced (CIAEH 2018). In the case of this island, it would be advisable to establish not only measures for recovery of financial costs but also for recovery of environmental costs.

Regarding cost recovery from collection and treatment in public networks, Tenerife island shows the highest recuperation, while El Hierro island has the lowest (see Table 6). The volume of treated wastewater has increased considerably since the 1990s, due to the continuous growth of water consumption and improvements in the regulation of wastewater treatment, regardless of its use (Khemlani et al. 2021). In most cases, water tariffs for the users do not contemplate how polluted the water is, household characteristics or volume of treated water (Hoque and Wichelns 2013; Molinos-Senante et al. 2013; Pinto and Marques 2015). Table 6 shows that, at least for El Hierro, La Gomera, La Palma, Fuerteventura and Lanzarote islands, it is urgent to improve cost recovery from wastewater systems by reviewing the tariffs and fees to the users.

Even though water reuse is increasing in the Canary Islands due to high rates of population and tourism, as well as improvement in technologies (Ruiz-Rosa et al. 2020), in general, cost recovery from this service is still low. It would be expected to grow in the future, not only because of higher water demand but also to accomplish the principles of the WFD. The limited integration of treated water into the water cycle is a common issue experienced in other islands around the world, such as in the cases of Crete (Tzanakakis et al. 2022), Taiwan (Shiu et al. 2017), or Mayotte (Mégevand et al. 2021).

Finally, it is difficult to compare upstream and downstream water supply for all the islands, as not all of them share the same system. Although the same methodology has been followed for each island, the information available and the cost recovery mechanisms implemented by water agents differ.

4 Conclusions

Cost recovery is a very useful tool that contributes to reaching good status of water bodies by the ‘Polluter Pays’ principle. The methodology for its establishment is based on three main steps: estimation of financial costs, estimation of environmental costs and estimation of resource costs once the water uses and services are described. Nevertheless, the estimation of each cost is complicated, due to many sources of information, and it depends on ease of access. In most cases, this data is not up to date or it is privately owned. Also, the insular character of the study area makes it difficult to compare, in general, cost recovery in all of the islands. Water management is different because water availability, sources and production mechanisms are not the same in all of them.

The divergent results obtained following the same methodology are due to the different public prices or rates on each island. For instance, La Gomera and El Hierro should review this policy of water prices, as there are almost no charges to the consumers for use of the water. The islands with higher populations (Gran Canaria and Tenerife) showed the best cost recovery results, since they have better and more mechanisms to charge for water services. Lanzarote and Fuerteventura showed the best cost recovery from desalination, as it is their main source of water supply, and it is well established. It is also crucial to improve cost recovery from wastewater collection and treatment, in order to have a more readily available volume of reused water.

Finally, it is noteworthy that our study introduces the novel application of the stochastic frontier model, which allows for the assessment of the efficiency of various water production techniques. This is particularly relevant in the Canary Islands' insular context, where diverse sources such as desalination and groundwater are prevalent. It is imperative to continue conducting studies like these to ensure the proper implementation of the Water Framework Directive in island spaces and to enhance cost recovery.

Acknowledgements The authors would like to thank the company Tragsatec for the information and documentation provided in relation to the data used for this study. Also, this research was partially supported by the European Union's Horizon 2020 research and innovation programme under grant agreement 101037424, project ARSINOE (Climate-resilient regions through systemic solutions and innovations).

Author Contributions All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by J.C. Santamarta, A. Hernández-Alemán, N. Cruz-Pérez, I. Gamallo-Paz, J. Rodríguez-Martín, I. Castellanos and A. García-Gil. The first draft of the manuscript was written by I. Gamallo-Paz and N. Cruz-Pérez and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Funding Open Access funding provided thanks to the CRUE-CSIC agreement with Springer Nature.

Data Availability The data that support the findings of this study are available from the corresponding author upon reasonable request.

Declarations

Ethical Approval This paper does not contain any studies with human participants or animals performed by any of the authors.

Consent to Participate N/A.

Consent to Publish N/A.

Competing Interests The authors declare no competing interests.

Open Access This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit <http://creativecommons.org/licenses/by/4.0/>.

References

- Aigner D, Lovell CAK, Schmidt P (1977) Formulation and estimation of stochastic frontier production function models. *J Econ* 6(1):21–37. [https://doi.org/10.1016/0304-4076\(77\)90052-5](https://doi.org/10.1016/0304-4076(77)90052-5)
- Alamanos A, Latinopoulos D, Mylopoulos N (2020) A methodological framework for an easy and reliable estimation of the full cost of irrigation water. *Water Environ J* 34(S1):529–539. <https://doi.org/10.1111/wej.12556>
- Albiac J, Calvo E, Kahil T, Esteban E (2020) The challenge of irrigation water pricing in the water framework directive. *Water Altern* 13(3):674–690
- Battese GE, Coelli TJ (1992) Frontier production functions, technical efficiency and panel data: With application to paddy farmers in India. *J Prod Anal* 3(1):153–169. <https://doi.org/10.1007/BF00158774>
- Belotti F, Daidone S, Ilardi G, Atella V (2012) Stochastic frontier analysis using Stata (CEIS Research Paper, Issue 251). Tor Vergata University, CEIS. <https://econpapers.repec.org/RePEc:rtv:ceisrp:251>. Accessed 22 Feb 2023
- Carvalho L, Mackay EB, Cardoso AC, Baatrup-Pedersen A, Birk S, Blackstock KL, Borics G, Borja A, Feld CK, Ferreira MT, Globevnik L, Grizzetti B, Hendry S, Hering D, Kelly M, Langaas S, Meissner K, Panagopoulos Y, Penning E, Solheim AL (2019) Protecting and restoring Europe's waters: an analysis of the future development needs of the Water Framework Directive. *Sci Total Environ* 658:1228–1238. <https://doi.org/10.1016/j.scitotenv.2018.12.255>
- CIAEH (2018) Plan Hidrológico de El Hierro. Ciclo de Planificación Hidrológica 2015–2021. Consejo Insular de Aguas de El Hierro, p 330
- CIAFV (2018) Plan Hidrológico de Fuerteventura. Ciclo de Planificación Hidrológica 2015–2021. Consejo Insular de Aguas de Fuerteventura, p 385
- CIALG (2018) Plan Hidrológico de La Gomera. Ciclo de Planificación Hidrológica 2015–2021. Consejo Insular de Aguas de La Gomera, p 374
- CIALP (2018) Plan Hidrológico de La Palma. Ciclo de Planificación Hidrológica 2015–2021. Consejo Insular de Aguas de La Palma, p 464
- CIALZ (2018) Plan Hidrológico de Lanzarote. Ciclo de Planificación Hidrológica 2015–2021. Consejo Insular de Aguas de Lanzarote, p 558
- CIATF (2018) Plan Hidrológico de Tenerife. Ciclo de Planificación Hidrológica 2015–2021. Consejo Insular de Aguas de Tenerife, p 960
- Coello-Bravo JJ, Márquez Á, Herrera R, Huertas MJ, Ancochea E (2020) Multiple related flank collapses on volcanic oceanic islands: Evidence from the debris avalanche deposits in the Orotava Valley water galleries (Tenerife, Canary Islands). *J Volcanol Geoth Res* 401:106980. <https://doi.org/10.1016/j.jvolgcores.2020.106980>
- Cortignani R, Dell'Unto D, Dono G (2018) Recovering the costs of irrigation water with different pricing methods: insights from a Mediterranean case study. *Agric Water Manag* 199:148–156. <https://doi.org/10.1016/j.agwat.2017.12.016>
- Cruz-Pérez N, Santamarta JC, García-Gil A, Rodríguez-Martín J, Miralles-Wilhelm F, Hernández-Alemán A, Aldaya MM (2022) Water Footprint of the Water Cycle of Gran Canaria and Tenerife (Canary Islands, Spain). *Water* 14(934):1–11. <https://doi.org/10.3390/w14060934>
- Custodio E, Cabrera MC, Poncela R, Puga LO, Skupien E, del Villar A (2016) Groundwater intensive exploitation and mining in Gran Canaria and Tenerife, Canary Islands, Spain: hydrogeological, environmental, economic and social aspects. *Sci Total Environ* 557–558:425–437. <https://doi.org/10.1016/j.scitotenv.2016.03.038>
- Dallavalle E, Cipolletta M, Casson Moreno V, Cozzani V, Zanuttigh B (2021) Towards green transition of touristic islands through hybrid renewable energy systems. A case study in Tenerife, Canary Islands. *Renewable Energy* 174:426–443. <https://doi.org/10.1016/j.renene.2021.04.044>
- Díaz FJ, Tejedor M, Jiménez C, Dahlgren RA (2011) Soil fertility dynamics in runoff-capture agriculture, Canary Islands, Spain. *Agr Ecosyst Environ* 144:253–261. <https://doi.org/10.1016/j.agee.2011.08.021>
- EU (2000) Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy. European Parliament, p 72. <https://eur-lex.europa.eu/eli/dir/2000/60/2009-06-25>. Accessed 15 Mar 2023
- Farrell MJ (1957) The measurement of productive efficiency. *J R Stat Soc Ser A (General)* 120(3):253–290. <https://doi.org/10.2307/2343100>
- Galioto F, Marconi V, Raggi M, Viaggi D (2013) An assessment of disproportionate costs in WFD: The experience of Emilia-Romagna. *Water (Switzerland)* 5(4):1967–1995. <https://doi.org/10.3390/w5041967>

- Gallego-Ayala J, Gómez-Limón JA (2009) Analysis of policy instruments for control of nitrate pollution in irrigated agriculture in Castilla y León, Spain. *Span J Agric Res* 7(1):24. <https://doi.org/10.5424/sjar/2009071-395>
- Gobierno de Canarias (2022) Anuario Energético de Canarias 2021. Consejería de Transición Ecológica, Lucha contra el Cambio Climático y Planificación Territorial, p 392
- Gohar AA, Cashman A, Ward FA (2019) Managing food and water security in Small Island States: New evidence from economic modelling of climate stressed groundwater resources. *J Hydrol* 569:239–251. <https://doi.org/10.1016/j.jhydrol.2018.12.008>
- Gómez-Gotor A, Del Río-Gamero B, Prieto Prado I, Casañas A (2018) The history of desalination in the Canary Islands. *Desalination* 428:86–107. <https://doi.org/10.1016/j.desal.2017.10.051>
- González-Morales A, Ramón-Ojeda AA (2019) La desalación de agua de mar en las Canarias Orientales: los casos de Lanzarote y Fuerteventura. *Agua y Territorio* 13:15–26. <https://doi.org/10.17561/at.13.3722>
- Guerrini A, Romano G, Leardini C (2018) Economies of scale and density in the Italian water industry: a stochastic frontier approach. *Util Policy* 5:103–111. <https://doi.org/10.1016/j.jup.2018.04.003>
- Gundelfinger-Casar J, Coto-Millán P (2018) Measuring the main determinants of tourism flows to the Canary Islands from mainland Spain. *J Air Transp Manag* 70:83–90. <https://doi.org/10.1016/j.jairtraman.2018.05.002>
- Hernandez Y, Guimarães Pereira Â, Barbosa P (2018) Resilient futures of a small island: a participatory approach in Tenerife (Canary Islands) to address climate change. *Environ Sci Policy* 80:28–37. <https://doi.org/10.1016/j.envsci.2017.11.008>
- Hoque SF, Wichelns D (2013) State-of-the-art review: designing urban water tariffs to recover costs and promote wise use. *Int J Water Resour Dev* 29(3):472–491. <https://doi.org/10.1080/07900627.2013.828255>
- Hughes SJ, Malmqvist B (2005) Atlantic Island freshwater ecosystems: challenges and considerations following the EU Water Framework Directive. *Hydrobiologia* 544(1):289–297. <https://doi.org/10.1007/s10750-005-1695-y>
- Jondrow J, Knox Lovell CA, Materov IS, Schmidt P (1982) On the estimation of technical inefficiency in the stochastic frontier production function model. *J Econ* 19(2–3):233–238. [https://doi.org/10.1016/0304-4076\(82\)90004-5](https://doi.org/10.1016/0304-4076(82)90004-5)
- Kanakoudis V, Tsitsifli S, Papadopoulou A (2012) Integrating the carbon and water footprints' costs in the water framework directive 2000/60/EC full water cost recovery concept: Basic principles towards their reliable calculation and socially just allocation. *Water (Switzerland)* 4(1):45–62. <https://doi.org/10.3390/w4010045>
- Khemlani N, Delgado Q, Soriano J, Peñate B, Minatta ABM (2021). Caso de Canarias: Ingenio e innovación en la cadena de valor del agua. 77. Banco Interamericano de Desarrollo, Las Palmas de Gran Canaria. <https://doi.org/10.18235/0003180>
- Kress N, Gertner Y, Shoham-frider E (2020) Seawater quality at the brine discharge site from two mega size seawater reverse osmosis desalination plants in Israel (Eastern Mediterranean). *Water Res* 171:115402. <https://doi.org/10.1016/j.watres.2019.115402>
- Laureti T, Benedetti I, Branca G (2021) Water use efficiency and public goods conservation: a spatial stochastic frontier model applied to irrigation in Southern Italy. *Socioecon Plann Sci* 73:100856. <https://doi.org/10.1016/j.seps.2020.100856>
- Macías Hernández AM (2009) La colonización europea y el derecho de aguas. El ejemplo de Canarias, 1480–1525. *Hispania - Revista Espanola de Historia* 69(233):715–738. <https://doi.org/10.3989/hispania.2009.v69.i233.118>
- Mégevand L, Martínez-Alarcón D, Theuerkauff D, Rivera-Ingraham GA, Lejeune M, Lignot JH, Sucré E (2021) The hepatopancreas of the mangrove crab *Neosarmatium africanum*: a possible key to understanding the effects of wastewater exposure (Mayotte Island, Indian Ocean). *Environ Sci Pollut Res* 28(43):60649–60662. <https://doi.org/10.1007/s11356-021-14892-5>
- Molinos-Senante M, Maziotis A (2019) Cost efficiency of English and welsh water companies: a meta-stochastic frontier analysis. *Water Resour Manage* 33(9):3041–3055. <https://doi.org/10.1007/s11269-019-02287-8>
- Molinos-Senante M, Hernandez-Sancho F, Sala-Garrido R (2013) Tariffs and cost recovery in water reuse. *Water Resour Manage* 27(6):1797–1808. <https://doi.org/10.1007/s11269-012-0111-4>
- Mylopoulos N, Fafoutis C (2012) Full cost recovery in the urban residential sector according to the Water Framework Directive. *Urban Water J* 9(3):161–176. <https://doi.org/10.1080/1573062X.2011.652131>
- PalmerosParada M, Randazzo S, Gamboa G, Ktori R, Bouchaut B, Cipolina A, Micale G, Xevgenos D (2023) Resource recovery from desalination, the case of small islands. *Resour Conserv Recycl* 199:107287. <https://doi.org/10.1016/j.resconrec.2023.107287>

- Pellegrini E, Dalmazzone S, Fasolino NG, Frontuto V, Gizzi P, Luppi F, Moroni F, Raggi M, Zanni G, Viaggi D (2023) Economic analysis under the Water Framework Directive: The state of the art and way forward. *Water* 15(23):4128. <https://doi.org/10.3390/w15234128>
- Pinto FS, Marques R (2015) Tariff structures for water and sanitation urban households: a primer. *Water Policy* 17:1108–1126. <https://doi.org/10.2166/wp.2015.188>
- Ruiz-Rosa I, García-Rodríguez FJ, Mendoza-Jiménez J (2016) Development and application of a cost management model for wastewater treatment and reuse processes. *J Clean Prod* 113:299–310. <https://doi.org/10.1016/j.jclepro.2015.12.044>
- Ruiz-Rosa I, García-Rodríguez FJ, Antonova N (2020) Developing a methodology to recover the cost of wastewater reuse: A proposal based on the polluter pays principle. *Utilities Policy* 65:101067. <https://doi.org/10.1016/j.jup.2020.101067>
- Sánchez-Benítez A, García-Herrera R, Vicente-Serrano SM (2017) Revisiting precipitation variability, trends and drivers in the Canary Islands. *Int J Climatol* 37(9):3565–3576. <https://doi.org/10.1002/joc.4937>
- Santamarta JC, Lario-Bascones RJ, Rodríguez-Martín J, Hernández-Gutiérrez LE, Poncela R (2014) Introduction to hydrology of volcanic islands. *IERI Procedia* 9:135–140. <https://doi.org/10.1016/j.ieri.2014.09.053>
- Santamarta JC, García C, Rodríguez-Lozano P, Rodríguez-Martín J, Cruz-Pérez N (2021) Water footprint in the water cycle of the Canary Islands. In: de Catalunya UP (ed) *II International Conference on Water and Sustainability*. <https://doi.org/10.3926/icws2021>
- Santamarta JC, Rodríguez-Martín J, Poncela R, Fontes JC, Lobo de Pina A, Cruz-Pérez N (2022a) Integrated water resource management in the Macaronesia. *Int Rev Civ Eng (I.R.E.C.E.)* 13(4):8. <https://doi.org/10.15866/irece.v13i4.21523>
- Santamarta JC, Calvo I, Rodríguez-Martín J, Cruz-Pérez N (2022b) Water status in the Canary Islands related to energy requirements. *Energ Effi* 15(13):12. <https://doi.org/10.1007/s12053-021-10016-7>
- Schallenberg-Rodríguez J, Veza JM, Blanco-Marigorta A (2014) Energy efficiency and desalination in the Canary Islands. *Renewable Sustain Energy Rev* 40:741–748. <https://doi.org/10.1016/j.rser.2014.07.213>
- Schmidt P, Sickles RC (1984) Production frontiers and panel data. *J Bus Econ Stat* 2(4):367–374. <https://doi.org/10.2307/1391278>
- Shiu HY, Lee M, Chiueh PT (2017) Water reclamation and sludge recycling scenarios for sustainable resource management in a wastewater treatment plant in Kinmen islands, Taiwan. *J Clean Prod* 152:369–378. <https://doi.org/10.1016/j.jclepro.2017.03.110>
- Tsitsifli S, Gonelas K, Papadopoulou A, Kanakoudis V, Kouziakis C, Lappos S (2017) Socially fair drinking water pricing considering the full water cost recovery principle and the non-revenue water related cost allocation to the end users. *Desalin Water Treat* 99:72–82. <https://doi.org/10.5004/dwt.2017.21552>
- Turner SWD, Hejazi M, Yonkofski C, Kim SH, Kyle P (2019) Influence of groundwater extraction costs and resource depletion limits on simulated global nonrenewable water withdrawals over the twenty-first century. *Earth's Future* 7(2):123–135. <https://doi.org/10.1029/2018EF001105>
- Tzanakakis VA, Angelakis AN, Paranychianakis NV, Dialynas YG, Tchobanoglous G (2022) Correction: Tzanakakis et al. Challenges and Opportunities for Sustainable Management of Water Resources in the Island of Crete, Greece. *Water* 14(7):1024. <https://doi.org/10.3390/w14071024>
- Wang L, Kong Y, Jiang J, Wei D, Li P, Yang S, Ting YP (2018) Optimal wastewater treatment using a packed-bed electrode reactor (PBER): from laboratory experiments to industrial-scale approaches. *Chem Eng J* 334:707–713. <https://doi.org/10.1016/j.cej.2017.10.124>

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Authors and Affiliations

Juan C. Santamarta¹  · Anastasia Hernández-Alemán²  ·
Noelia Cruz-Pérez¹  · Isabel Gamallo-Paz¹  · Jesica Rodríguez-Martín¹  ·
Ignacio de Martín-Pinillos Castellanos³  · Alejandro García-Gil⁴ 

✉ Juan C. Santamarta
jcsanta@ull.es

Anastasia Hernández-Alemán
anastasia.hernandez@ulpgc.es

Noelia Cruz-Pérez
ncruzper@ull.edu.es

Isabel Gamallo-Paz
igamallo@fg.ull.es

Jesica Rodríguez-Martín
jrodrima@ull.edu.es

Ignacio de Martín-Pinillos Castellanos
ipinillo@ull.edu.es

Alejandro García-Gil
a.garcia@igme.es

¹ Department of Agricultural and Natural Environmental Engineering, University of La Laguna (ULL), Tenerife, Spain

² Institute of Tourism and Sustainable Economic Development (TiDeS), University of Las Palmas de Gran Canaria (ULPGC), Gran Canaria, Spain

³ Department of Agricultural and Natural Environmental Engineering, University of La Laguna (ULL), La Laguna, Tenerife, Spain

⁴ Geological Survey of Spain (IGME-CSIC), Ríos Rosas St. 23, 28003 Madrid, Spain