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Cost–Benefit Analysis of Wastewater Reuse in Puglia, Southern Italy

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Abstract: A comprehensive economic analysis of the associated costs and benefits derived from wastewater treatment is a prerequisite for ensuring long-term economic, environmental, and social sustainability. This study aims to improve the economic evaluation of wastewater reuse. A methodological framework is presented for the application of cost-benefit analysis to wastewater project plants. The method considers two alternative scenarios for the irrigation use of treated water: (i) for newly irrigated land; and (ii) as an alternative to current groundwater sources. A case study is carried out in Puglia, Southern Italy, where two thirds of irrigation water comes from groundwater. The results show that improved urban wastewater treatment would increase the regional availability of irrigation water by 60 million m^3 per year, about 10% of the overall irrigation water demand. While treatment costs are highly dependent on the incoming effluent quality and plant size, the benefits are quite stable. These results point to a case-specific analysis, whereby the economic convenience of wastewater reuse could be assessed against the local context.

Keywords: wastewater reuse; cost-benefit analysis; valuing water; groundwater; irrigation

1. Introduction

There has long been a consensus that the direct reuse of treated wastewater for agricultural purposes offers a realistic supply alternative in many Mediterranean regions faced with water scarcity. According to the European Wastewater Directive [1], all wastewater must be treated before it can be disposed of in natural water bodies. However, before treated wastewater can be directly used in agriculture, it requires an additional disinfection treatment to convert it to reclaimed wastewater. In Europe, reclaimed wastewater is used for agricultural irrigation, landscape irrigation, industry, groundwater recharge, and non-potable urban uses. Although technological progress ensures that recycling is safe, the total volume of treated wastewater reuse is only 2.4% of the treated effluent [2].

Wastewater treatment is expected both to increase water availability and enhance the environment, as recognized by the European Water Framework Directive [3]. The main advantage of improved treatment is that it reduces the amount of pollutants released, especially into surface water bodies [4]. Nevertheless, round the coastlines of many Mediterranean countries, groundwater salt intrusion is also a prominent threat and the quality of irrigation water is declining. Wastewater reuse might play a key role in those regions affected by groundwater over-exploitation. Indeed, treated wastewater can be used as an artificial aquifer to recharge groundwater [5] as well as an alternative water resource for irrigation where agricultural demand has led to the over-abstraction of groundwater [6,7].

Nevertheless, water reuse projects may fail for various reasons. One is the lack of popular support, because the perceived risk of poor water quality leads to problems with acceptance [8,9]. The local capacity to develop suitable technologies can also be a problem in developing countries [10]. On top of these issues, the main driver of the implementation of wastewater reuse is the economic feasibility of treatments along with the economic impact of water scarcity. To ensure long-term economic, environmental, and social sustainability, a comprehensive economic analysis of the associated costs and benefits derived from wastewater treatment is a pre-condition. This is also consistent with the approach outlined in the European Union Water Framework Directive [3].

There is vast literature dealing with wastewater reuse in agriculture. The potential for effluent reuse in Europe, and in Italy specifically, has generally been evaluated from an agronomic [11,12] and technical point of view [7,13–15]. However, less attention has been paid to economic assessment. The economic feasibility of wastewater treatment has usually been assessed by comparing the costs (at source) of the additional treatment of effluent for final polishing with the tariff (on site) of the water currently used [16,17]. Papa et al. [18] recently considered the costs of a hydraulic system for conveying reclaimed wastewater to irrigation networks. However, a rigorous economic assessment should compare, at the same stance, the costs and benefits derived from wastewater treatment while simultaneously considering the real economic value of water as a productive factor (i.e., its use value) and as an environmental public good (its non-use value).

Nevertheless, while market-based information is needed to assess the benefits associated with treatment to enable wastewater irrigation, indirect methods must be applied to assess the non-use benefits (e.g., recreational and environmental) derived from wastewater reuse. For instance Alcon et al. [19], estimated the non-market (i.e., environmental) benefits that society attaches to the use of reclaimed wastewater for irrigation in the Segura River Basin in southeastern Spain, using the contingent evaluation method (see [20] for a review). Birol, et al. [21] estimated the total costs and benefits of using treated wastewater to artificially recharge the Akrotiri aquifer in Cyprus. Indeed, an assessment of the use and non-use economic benefits that may arise as a result of the proposed aquifer management plan is carried out using choice experiments (The contingent valuation and choice experiments are both survey-based stated preference techniques in which respondents are asked to express their preferences directly). Alternatively, Molinos-Senante, et al. [22] used the concept of shadow price to quantify the environmental benefits derived from wastewater treatment. The value of these represents the environmental damage avoided, or environmental benefit derived, from the removal of pollutants during wastewater treatment). Although a comprehensive assessment of the benefits, including environmental benefits, would be a more policy-relevant approach, the lack of market-based information for environmental benefits might lead to inaccurate estimation [17,22].

In this context, this research aims to improve the economic evaluation of directly treated wastewater reuse. First, we draw up a methodological framework for the application of cost-benefit analysis (CBA) to wastewater project plants. We investigate two hypothetical scenarios for the irrigation usage of reclaimed wastewater: (i) for newly irrigated land; and (ii) as a complementary source to current irrigation groundwater resource. The direct value and the option use value of preserving the groundwater water quality (i.e., salinity) for irrigation are estimated according to the tested hypotheses. Contrary to the studies mentioned above, in this research, we assess the real economic benefits of reclaimed wastewater as a productive factor for irrigation. These estimated benefits are aggregated over the population of the relevant farms and weighed against the costs of providing the reclaimed water at the plant gate. The treatment costs are analyzed in relation to the incoming effluent quality standard, with or without oxidation and sediment filtration in addition to the treatment of coagulation and disinfection. The scale effect of plant size on treatment costs is analyzed, which represents an innovative approach. A case study is carried out in the Puglia region Southern Italy, where two thirds of irrigation water comes from groundwater.

A wider goal of this research is to provide local policy makers with a comprehensive economic analysis of treated wastewater reuse in agriculture. The results are nevertheless expected to be of broader relevance, particularly to other water scarce regions facing similar water management issues.

The outcome of this study can be directly applied to other Italian regions, while the proposed methodology could also be applied in the overall European context, given that the Italian National regulations derive from the application of European Directives [1,3]. Environmental Protection Agencies in many other countries around the world, including the U.S., have also developed wastewater treatment standards to be applied at the country or state level.

2. Background

2.1. Irrigation Water and Groundwater Over-Exploitation in Puglia

Puglia exhibits a Mediterranean climate, characterized by warm to hot, dry summers and mild to cool, wet winters. Irrigation is important to the overall economy of the region, to especially agriculture. In 2009/2010, the total irrigated land amounted to 238,546.02 ha [23] (Figure 1). Permanent crops such as olive and grape are widespread, followed by fresh-cut vegetables (broccoli, carrot, spinach, artichoke, asparagus, etc.) and processing tomatoes. Overall, these crops account for 80% of the region's irrigated land.

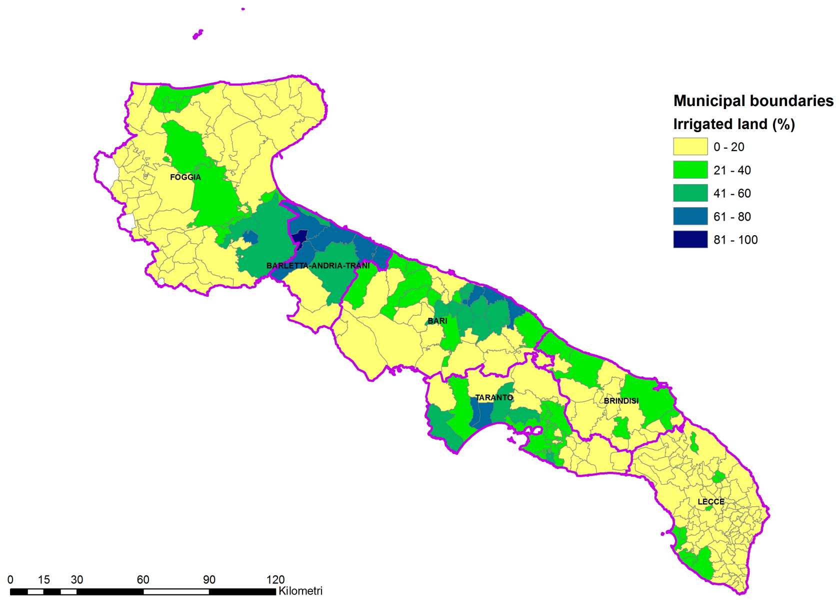


Figure 1. Puglia region with provinces: Irrigated land over utilized agricultural area (2009/2010).

The irrigation volume data are based on indirect estimation. A few attempts have been made to estimate the irrigation volume (see, for instance, [24]). The most recent is the MARSALa model [25], which reports 655.29 million m^3 in 2009/2010. The average farm size for irrigated land is less than 5 ha, with 87,463 farms applying irrigation (32.2% of all farms). Moreover, half of farms that use irrigation have on-farm wells, while less than 30% are connected to collective infrastructures.

Groundwater supplies about 55% of the region's total water consumption of about 1500 million m^3 [24]. More than 60% of exploited groundwater is used for irrigation, and abstraction increases considerably in severe drought periods, as was the case in 1982, 1988,1989, and 2002 [24]. In many areas where groundwater is the main freshwater source, pumping rates exceed the natural recharge rate and cause continuous water-table drawdown, well depletion, increased pumping costs, and severe seawater intrusion in coastal areas.

Contrary to what has occurred in large surface water development projects (i.e., implemented by public agencies under the direct control of central authorities), groundwater resources have been exploited almost everywhere by a large number of public and private small users, thus creating a situation that is difficult to monitor and regulate. In this case, groundwater resources can be considered as typical common pools that are exploited with the use of increasingly simple and low-cost technologies. The lack of an adequate institutional framework and an effective monitoring and control system create the conditions for potential over-exploitation and quality degradation of aquifers. Although drilling private wells is subject to public authorization or licensing, in many cases, the monitoring and control system is fragmented and the cost might be prohibitively expensive for public authorities. Additionally, as in the case of Puglia, many regions face inconsistency because surface and groundwater are managed by different institutions.

2.2. Treated Wastewater Reuse in Puglia: Potential Availability

The reuse of treated wastewater in agriculture, as well as in other sectors such as industrial, recreational, and environmental, can help to protect surface water bodies and aquatic and terrestrial ecosystems. Wastewater treatment for reuse is also a critical step in the so-called "integrated cycle" of water resources management, and allows the achievement of important environmental objectives in terms of both water quality and quantity.

From a quantitative point of view, effluent reuse leads to the closure of the water cycle, which increases the water supply from unconventional sources and theoretically reduces the exploitation of surface and groundwater.

A state-of-the-art study in Puglia is reported in the Water Protection Plan [24], which provides an updated census of all wastewater treatment plants for which effluent reuse in agriculture could be implemented immediately (all plant upgrading works have already been carried out) or in a short time (minimal plant upgrading is required). Based on these data, we estimated, at the regional scale, the volume of reclaimed water potentially available at the plant gate through existing facilities ("current scenario" in Figure 2) as well as the expected volume available after the upgrading of a number of plants ("future scenario"). The results for all provinces of Puglia are reported in Figure 2.

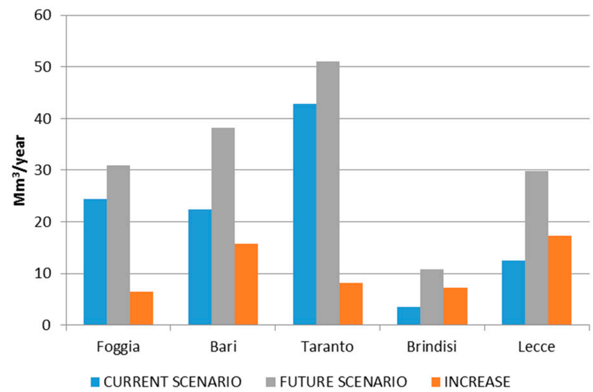


Figure 2. Reclaimed wastewater in Puglia.

The potential current amount of reclaimed wastewater available at the plant gate is 100 million m^3 across the region. Plant upgrading could increase this to 160 million m^3 [26]. Despite such availability, direct reuse of treated wastewater remains little more than a promising policy. In fact, the up-to-date figure (2010/2011) shows that the actual amount of reused treated wastewater is only 5 million m^3 per year [27].

A real example of reuse in agriculture is provided by a medium-sized plant located in the municipality of Fasano, a town with 35 thousand inhabitants not far from the Adriatic coast. The economic costs associated with treating, stocking, and delivering reclaimed water have been assessed [28]. In 2007, the costs of treatment in accordance with the law for reuse in agriculture amounted to 0.15 €/m^3 for 600 thousand m^3 of reclaimed wastewater (60% of operational capacity). The average cost of treatment is greatly affected by the annual volume of reclaimed wastewater.

2.3. Research Question

Despite the high water demand, the wastewater reuse of 160 million m^3 does not takeoff.

In the literature, the principal open policy question that remains is which strategies could be pursued at an institutional level (European, national and regional) to improve the acceptance and diffusion of wastewater reuse? Within this framework, our study deals with the following two issues. (i) The development of a regional CBA to promote and orient local studies, for instance through a downscaling process, to facilitate the assessment of improved implementation strategies; (ii) How multidisciplinary investigations, between, for instance, engineering and economics, can be enhanced to merge the issues relating to treatment with the economic aspects of reclaimed wastewater reuse.

3. Methodology

3.1. Framework

The CBA starts from the premise that an investment should only be commissioned if the benefits exceed the aggregate costs [22]. Accordingly, the costs and benefits of each proposal are compared using a common analytical framework. Although there would be several end-users for effluents reuse, our analysis is focused on irrigation use. Obviously, for the CBA, the benefits and costs must refer to the same situation [29]. The primary discussion is between private and social accounting perspectives. The private perspective taken in this study measures the impacts in terms of prices faced by the economic actor being studied. The interest rate is the most common element of a CBA that is adjusted from an accounting point of view [21]. Second, this study takes a long-term perspective that allows for changes in wastewater treatment technology. Plant capacity also varies over the long-term. Third, the commensurability of the place, form, and time of water sources is established. The most relevant aspect is probably the location where the costs and benefits are evaluated, namely on-site versus at-source. This study takes the plant gate as the reference point of monetary accounting. The cost-benefit comparison is performed in terms of raw water supplies at the plant gate. This excludes the transportation costs to the site of use (i.e., farm gate), and of storing and pressurizing the raw water to convert it into the commodity with the place, time, and form attributes desired by the farmers. Likewise, the benefits of reclaimed water for irrigation use do not take into account the value at the point of use. Nevertheless, we consider reclaimed wastewater as a steadily available source over the years, thus ensuring the irrigation water supply. Consequently, we also account for the economic value of guaranteeing the irrigation water supply [30]. Finally, the quality of the reclaimed water complies with Italian law.

Table 1 presents the two alternative hypotheses for the irrigation use of treated wastewater: (i) for newly irrigated land (Hypothesis I); and (ii) as complementary to current groundwater sources (Hypothesis II).

The first hypothesis takes the simplest case, in which rain-fed farmland is provided with reclaimed wastewater. In this case, the costs at the plant gate would include the costs of treatment and the benefits are those associated with the direct use of reclaimed water for irrigation. The second hypothesis reflects the regional government's aim of reducing groundwater exploitation by increasing direct wastewater reuse [24,27].

While the regional government's aim is valuable, its strategy is based on the unlikely assumption that increasing the irrigation water supply will directly reduce groundwater exploitation. In fact, at a basin scale, it has not yet been demonstrated that irrigation water demand can be reduced by increasing the supply from non-conventional sources. In water-stressed regions, any increase in supply will also lead to an increase in demand unless a ceiling on water consumption is enforced [31]. For instance, we suggest a constraint on irrigated land to ensure the use of reclaimed wastewater actually saves on groundwater. On the one hand, the costs of on-farm monitoring, control, and sanctioning should be accounted for. On the other hand, the benefits of preserving groundwater salinity (i.e., option value) should be added to the direct benefits derived from irrigation.

Table 1. Cost-benefit analysis framework.

Hypothesis I	Hypothesis II
All treated wastewater intended for newly irrigated land	*All treated wastewater to reduce groundwater usage*
Costs	
-treatments (three alternatives)	-treatments (three alternatives) -on-farm monitoring and control (constraints on irrigated land)
Benefits	
-economic value of irrigation	-economic value of irrigation -economic value of good groundwater quality (salinity)

Finally, a cost-benefit comparison is carried out that takes into consideration the scale effect of plant size. The population equivalent (PE) is the unit applied to wastewater to describe the size of package sewage treatment plants. The average cost per m^3 of reclaimed wastewater decreases as the PE increases. The break-even point is where the costs equal the benefits. This point is used as the PE threshold from which a given plant upgrading starts to become economically feasible.

3.2. Economic Appraisal of Costs

3.2.1. Treatment Cost for Wastewater Reuse

The evaluation of costs for the Future Scenario (i.e., technological upgrading of current plants) took into account the "additional" processes of tertiary treatments necessary for reusing the effluent in agriculture. In other words, we did not count the capital and management costs of building new plants, only the cost of upgrading the existing treatment plants to enhance the required effluent quality. Italian laws (D.L.152/06 and D.M.185/2003) establish the effluent standard quality requirements for surface water discharge (T1), ground surface discharge (T2), and reuse (T3). These thresholds are shown in Table 2.

Table 2. Comparison of effluent standard quality requirements for discharge to surface water bodies (T1), ground surface (T2), and reuse (T3).

Parameter	Unit of Measurement	T1	T2	T3
pH	-	-	6–8	6–9.5
SAR (Sodium Adsorption Ratio)	-	-	10	10
Total Suspended Solids	mg/L	$\leq$35	25	10
BOD5 (Biochemical Oxygen Demand)	mg O_2/L	$\leq$25	25	20
COD (Chemical Oxygen Demand)	mg O_2/L	$\leq$125	100	100
total phosphorus	mg P/L	-	2	2
total nitrogen	mg N/L	-	15	15
pathogens (Escherichia coli)	UFC/100 mL	-	<5000	10

For the treatment plants that already provide effluents at T1 or T2 quality standards, the additional treatments necessary to reach the T3 standard are shown in Table 3. T2 effluents require only physical-chemical treatments (coagulation and an adjustment for filtration and disinfection) to achieve the T3 quality level, but T1 effluents also require biological treatments to remove nutrients such as phosphorus and nitrogen (i.e., denitrification, nitrification, and dephosphatisation).

Table 3. Treatment stages and processes necessary for the achievement of T3 quality standards.

Treatment Stages for Upgrading Adaptation of Sewage Treatment Plants			Quality Standard of Effluent	
			T1	**T2**
Biological treatment	Nitrogen removal	Denitrification	Required	Not required
		Nitrification	Required	Not required
	Dephosphatisation		Required	Not required
Physical-chemical treatment	Total suspended Solids removal	Filtration	Required	Enhanced
		Coagulation	Required	
	Disinfection		Enhanced	

According to the effluent quality standards, various investments need to be undertaken to reach the T3 quality standard. Furthermore, the usability coefficients of the reclaimed wastewater will differ according to the scenarios to be tested (see Table 1). While a steady supply of reclaimed wastewater can be provided over the year, irrigation demand exhibits seasonal fluctuation. If all treated wastewater is intended for newly irrigated land, the operational capacity of the plant should be set to the month of peak demand. This implies lower usability coefficients for reclaimed wastewater during periods of lower demand. In contrast, in the case of already irrigated farms that rely on groundwater, the operational capacity of the treatment plant could be set so that the usability coefficient increases. Table 4 presents some example usability coefficients for the study area.

Table 4. Usability coefficient for "irrigation" (Hypothesis I) and "integrated irrigation" (Hypothesis II).

	April	May	June	July	August	September	October
Hypothesis I	0.22	0.61	0.96	1	0.96	0.48	0.13
Hypothesis II	0.36	1	1	1	1	0.8	0.2

Source: Our elaboration.

The cost evaluation was carried out in the following steps.

(1) We identified two main categories of cost: fixed costs, which include civil works and electromechanical works, and variable costs, which include staff, maintenance, energy costs, and reagents.

(2) We assigned an average value for the volume of available after treatment, shown in Table 5, according to the plant capacity expressed in PE. We obtained the annual volume for both hypotheses by multiplying the daily water availability by the usability coefficient (Table 4).

(3) We considered the presence and characteristics of tertiary treatment in each plant scheme, particularly the presence or absence of a sedimentation basin or tank that can be used for nitrification and denitrification, working at a temperature of 15 °C or 20 °C.

(4) We evaluated the investments necessary to implement gravity filtration or pressure units with reference to the plant potential in terms of the PE. The estimated costs of these upgrades show some scale effects: pressure filters are advantageous for installations ranging from 2000 to 100,000 PE while gravity filters are better for higher PEs.

(5) We identified the capital and operating costs of upgrading treatment plants according to T1 and T2 effluent quality standards. The unit prices of materials and electromechanical equipment were taken from the official Chamber of Commerce regional price list in 2012.

(6) We collected market information aimed at comparing prices among leading technology retailers and civil works firms. From these values, we derived the unit costs of the civil works and electromechanical devices necessary to upgrade the plants. This survey allowed us to define the "feature-cost" curves for individual treatment stages.

(7) We assessed management and operational costs with reference to personnel, reagents, energy, and maintenance. To estimate the maintenance costs, we assumed a 25-year "useful life" for

civil works and an annual maintenance rate of 1%; an annual rate of 5% was applied for electromechanical devices with eight years of "useful life".

(8) We considered a straight-line depreciation rate of 4% for civil works and 12.5% for electromechanical devices.

Table 5. Average water availability at plant gate.

Plant Capacity (EP)	Water Availability (m^3/Day)	Potential Reuse in Agriculture (m^3/Year)	
		Hypothesis I	*Hypothesis II*
2000	432	57,672	70,848
5000	1080	144,180	177,120
10,000	2160	288,360	354,240
20,000	5760	768,960	944,640
30,000	8640	1,153,440	1,416,960
40,000	11,520	1,537,920	1,889,280
50,000	14,400	1,922,400	2,361,600
70,000	20,160	2,691,360	3,306,240
100,000	28,800	3,844,800	4,723,200
250,000	90,000	12,015,000	14,760,000
500,000	180,000	24,030,000	29,520,000

3.2.2. On-Farm Monitoring and Control

As Field and Field [32] point out, people tend to believe that enacting a law automatically rectifies the problem it is meant to address. The implementation and effectiveness of limiting groundwater use is dependent on the enforcement capacity, sanctioning systems, and the amount of information and management required. As mentioned in Section 2.1, a key issue in groundwater management is the size of the groundwater user community. Groundwater aquifers can be very small, with only tens or hundreds of users, but generally, as in the case of Puglia, there are numerous individual users. Enforcement ultimately requires energy and resources, and thus is a costly activity.

To limit the amount of groundwater used on irrigated land, the following steps should be taken, in addition to ensuring that groundwater is replaced by reclaimed wastewater: (i) initial allocation; (ii) a mechanism for registration and maintenance; (iii) a monitoring system; (iv) enforcement of the limits set by the individual; and (v) a credible system of sanctions.

The implementation of an on-farm monitoring and control system typically involves a fixed component such as the installation of measuring devices, setting up the administration and facilities, and a variable component that increases with the water volume (i.e., monitoring and collection activities). Monitoring and detection may include measuring the performance of water users and monitoring their compliance with regulations, and also the development of monitoring technologies [33]. The costs of sanctions include prosecution, inducement, and conflict resolution costs if a lack of compliance is detected.

While specific studies for the case area are not available, we used the figures reported in the literature that deal with the cap and trade mechanisms for irrigation water. McCann et al. [33] provide examples for Colorado and California where the average costs ranged from 6% to 8% of the water value.

3.3. Assessment of Benefits

3.3.1. Irrigation Water Value

The economic benefits of wastewater reuse in agriculture are linked to the irrigation water value. Therefore, the economic value is the value of its use as input for irrigation. Irrigation can increase crop yields and reduce seasonal yield variations due to the uneven rainfall pattern of the Mediterranean climate.

The main issue for assessing the economic value of water for agriculture is the lack of competitive markets for the resource. Therefore, appraisal methods need to be applied. Young [29] compared the advantages and shortcomings of a number of methodologies. Among the different methods available, the hedonic pricing method was selected for this study.

The basic premise of the hedonic pricing method is that the price of a marketed good is related to its characteristics, or the services it provides. For example, the price of farmland reflects the characteristics of that land—fertility, slope, location, etc.—as well as the bundled water availability. Therefore, we can value the individual characteristics of land according to the price that people are willing to pay for land with those characteristics. In this case, keeping all other factors invariant, the difference (if any) in the market for irrigated and rain-fed land can serve as a measure of how irrigation water directly affects the land price.

The hedonic method estimates the water value at the source because buyers and sellers of land are assumed to incorporate an estimate of the expected water cost in their calculation of expected future net rents from land and water [29]. Berbel and Mesa [34] and Latinopoulos et al. [35] applied the hedonic pricing method to assess the value of irrigation water in Mediterranean regions.

In this research, we followed the hedonic pricing method applied by Giannoccaro et al. [36] in an analysis in the province of Foggia, focusing on the largest irrigated area of Puglia where the irrigation service is provided and managed by the Reclamation and Irrigation Board of Capitanata (CBC). The CBC adopts volumetric block tariffs, whereby farmers pay according to their actual consumption [37]. A metering system called Acqua-tool has been implemented over the last few years to record individual water use. A three-tiered pricing structure is applied, with a first block of 2050 m^3/ha at a lower tariff (0.12 €/m^3), sufficient to cover running costs, a second block from 2051 up to 4000 m^3/ha, available at an intermediate tariff (0.18 €/m^3), and amounts in excess of that at a higher tariff (0.24 €/m^3). The average irrigation water use amounts to 2870 m^3/ha [25] which makes a weighted fee of 0.14 €/m^3.

Giannoccaro et al. [36] compared the rental price of rain-fed and irrigated farmland. The differences in altitude (hill and plain) and crop systems (arable and permanent) were taken into account in the analysis, and the economic value of guaranteed supply was assessed. An average irrigation water value was calculated for the province of Foggia for the steady average volume provided by the CBC.

3.3.2. Economic Value of Good Groundwater Quality Status

At present, the regional Water Protection Plan [24] does not provide a quantitative value for groundwater over-abstraction, or for the available water supply or annual natural recharge. Data on salinity are available for monitoring groundwater status, especially in areas near seashores, because salinization is considered a direct effect of over-abstraction. When the annual natural recharge capacity is smaller than the amount abstracted, seawater infiltrates into the aquifer and increases the groundwater salinity [38].

Groundwater salinization is represented by the effect of irrigation with brackish water on the crop yield. The extensive literature on this subject generally recognizes that there is an inverse relationship between the salinity of irrigation water and annual crop yields [39].

Externalities caused by over-abstraction represent a cost for farmers, who actually “forego” the use of a portion of the resource (or its good quality) that is supposed to be consumed in the future. In the presence of salinization along seashores, over-abstraction reduces the groundwater quality. Consequently, over-abstraction that exceeds the natural groundwater capacity entails a future cost for the farmers in terms of deteriorating water quality. The option value expresses the economic difference between the benefits derived by current and future use of the resource, and can be compared by calculating the farmers’ future discounted revenues due to reducing current abstraction to maintain an adequate salinity level.

The option value was calculated as the difference between the actualized net margin (NM), at a discount rate r, calculated for each of the selected management actions S: (i) with the implementation of the action; and (ii) without the implementation of the action.

$$\text{Option value } = \sum_t \left[\Delta NM^S t(1+r)^{-t}\right] \quad (1)$$

Empirical calculations were performed for a representative farm over a 25-year timeframe [40]. This is in line with the lifetime of wastewater project plants.

The investigated farm was located at Loc. Inacquata, 5 km from the coast of Zapponeta, and adjacent to Carapelle stream. The ground level was about 5 m above sea level, and the well depth was about 50 m. Available official data on the quality of groundwater (the only water available for irrigation) were not available. Based on the data provided by the holder of the farm, the level of salinity at the end of the 1990s was about 1.6–1.7 dS/m, whereas by 2011 it was in the range 2.2–2.3 dS/m. This indicates that there has been a deterioration in the water quality (equal to an average annual increase in salinity of 0.04 dS/m) due to the over-exploitation of the resource for irrigation purposes.

The agricultural holding included a farmstead, a greenhouse and 20 ha of arable land. The pumped water was stored in a small reservoir, and the annual average volume was approximately 25,000 m^3. The average pumping cost was about 0.14 €/m^3. The only irrigated crop was the tomato crop for industrial processing, which was grown in a four-year rotation with wheat to prevent soil fatigue problems and soil salt accumulation.

4. Results

4.1. Treatment Costs

In this section, we report the cost evaluation results for a few of the analyzed cases and compare the additional costs of upgrading a facility that meets T1 quality requirements with those of a facility that meets T2 quality requirements. For each of the four cases, the cost results are plotted as a function of the plant's potential, expressed as the PE, to account for economies of scale.

Costs of upgrading were estimated for:

Alternative 1 (Alt 1): Wastewater treatments that comply with "T1" requirements and provide primary sedimentation at temperature of 15 °C;

Alternative 2 (Alt 2): Wastewater treatments that comply with "T1" requirements and provide primary sedimentation at temperature of 20 °C;

Alternative 3 (Alt 3): Wastewater treatments that comply with "T2" requirements and apply a filtration process; and

Alternative 4 (Alt 4): Wastewater treatments that comply with "T2" requirements and do not apply a filtration process.

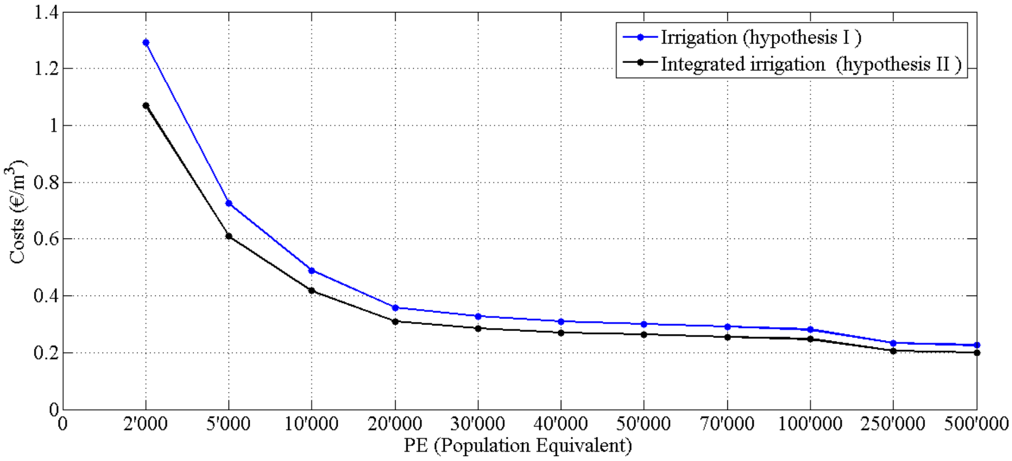
Figure 3 shows the results in terms of cost per m^3, as a function of plant capacity (PE), under each hypothesis (Hypothesis I (blue line) and Hypothesis II (black line)).

The additional cost of upgrading Alt 1, accounting for UV disinfection using high-dosage reagents, is shown in Figure 3a. For both lines, the costs are high for small plants (under 20,000 PE), whereas larger plants show the effects of economies of scale.

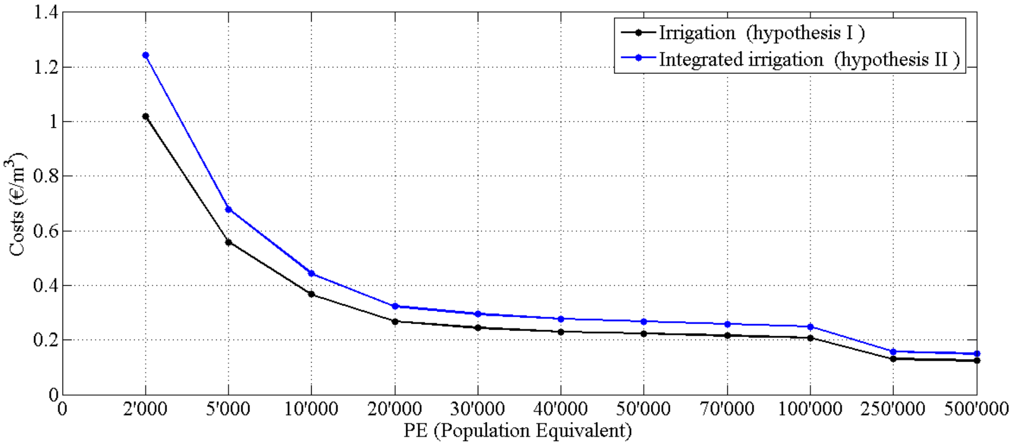
The additional cost of upgrading Alt 2, accounting for UV disinfection using high-dosage reagents, is shown in Figure 3b. The average cost decreases overall. The scale effect is also shown.

The additional cost of upgrading Alt 3, accounting for UV disinfection, filtration, and high-dosage reagents, is shown in Figure 3c. There is a huge decrease in the average cost of treatment when the incoming effluent quality is higher, namely at T2 standard. Scale effects are less obvious.

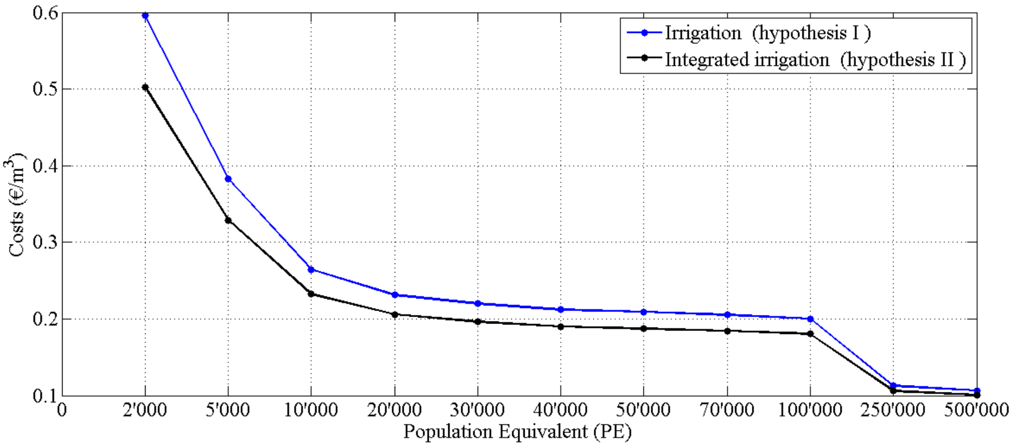
The additional cost of upgrading Alt 4, accounting for UV disinfection, using high-dosage reagents but without filtration, is shown in Figure 3d. This case shows the lowest average cost of treatment, below 0.20 €/m^3 at 10,000 PE plant capacity. There are no scale effects from a plant capacity of 30,000 PE.



(**a**)

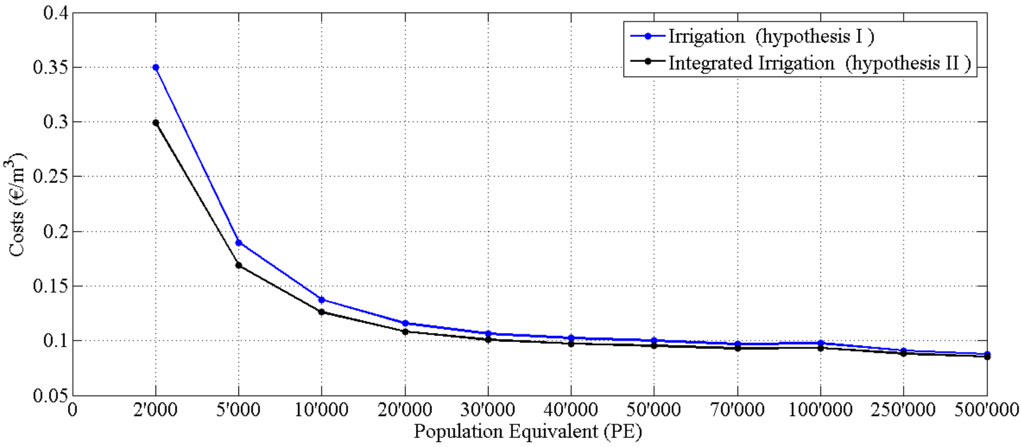


(**b**)



(**c**)

Figure 3. *Cont.*



(**d**)

Figure 3. Estimated costs of reclaimed wastewater at plant gate: (**a**) Alt 1; (**b**) Alt 2; (**c**) Alt 3; and (**d**) Alt 4.

Specific details about the procedure and the amounts used for the cost evaluations in Figure 3 are provided in a separate Supplementary Materials. The most important outcome of the study is summarized by the significant scale dependence of costs on the plant size; that is, on the population equivalent. Such evidence was obtained by an extensive cost accounting analysis performed on real design cases.

4.2. Benefits

The first result refers to the economic value of irrigation water. Table 6 reports the monetary values for irrigation water according to the crop and altitude in the province of Foggia. The values range from 0.15 to 0.23 €/m^3 on plain arable and permanent land, respectively.

Table 6. Economic appraisal of irrigation water in the province of Foggia.

Crop	Altitude	Δ of Ground Rent Irrigated/Rain Fed	Annual Equivalent Value [a]
		(€/ha)	(€/m^3)
Arable	hill	575	0.21
	plain	407	0.15
Permanent	hill	490	0.18
	plain	620	0.23

Source: [36]; average annual volume 2750 m^3/ha.

Using the values in Table 6 to infer the values for all irrigated land across the province, the average estimated value is 0.19 €/m^3 while guaranteeing the water supply is estimated at 0.02 €/m^3 for a steady annual volume of 2,475 m^3/ha [36]. Considering a steady supply of wastewater over the years, the average benefit derived from irrigation wastewater amounts to 0.21 €/m^3 with an annual average volume of 2475 m^3/ha.

The second finding refers to the benefits of maintaining a good level of salinity in the groundwater. The lower the salinity, the higher the value of irrigation water. If reclaimed wastewater were to reduce groundwater usage, there would be an additional benefit from improving the groundwater quality, provided that on-farm groundwater use decreased.

The analysis starts with the current salinity status (1.7–2.2 dS/m). The findings under the different groundwater use constraints, over a 25-year period, are reported in Table 7. If the current level of groundwater abstraction is reduced to preserve its status, an annual reduction of 2080 m^3 should be applied to the level of current groundwater extraction (25,000 m^3), which is replaced by reclaimed wastewater. The average monetary benefit is estimated at 0.22 €/m^3 and 0.02 €/m^3 is the proportional (8.3% of 0.21 €/m^3) direct use value.

Table 7. Benefits linked to the maintenance of good salinity status (timeframe = 25 years).

Salinity Status	**Scenario**	**Salinity (dS/m)**	**Yield Response to Salinity**	**NPV (Discount 5%) (€)**	**Overall Groundwater Extraction (m^3)**	**Annual Saving on Groundwater (m^3)**	**ΔNPV/Water Unit Saved (€/m^3)**
natural	restoring	<1.6	1	190,550	552,500	3900	0.19
current	preserving	1.7–2.2	0.95	197,521	598,000	2080	0.22
forecasted	no action	2.3–3.3	0.80	178,909	650,000	None	-

Source: Adapted from [40].

To restore the natural salinity level, greater groundwater reduction would be necessary (3900 m^3) and the benefit would amount to 0.19 €/m^3. The direct use value is estimated as 0.03 €/m^3.

The discount rate of 5% reflects the private point of view, in line with other research work [41–43], which in turn means that preserving rather than restoring is the most convenient means of saving groundwater.

4.3. Cost-Benefit Comparison

The break-even point for each hypothesis of the analysis is estimated by comparing the costs and benefits, including scale effects. In other words, we show that the PE capacity can be used to determine the size at which, according to the treatment features, it is economically convenient to reuse wastewater for agriculture. Table 8 shows the economic feasibility of wastewater reuse in Puglia.

Table 8. Economic Feasibility.

	Costs				**Benefits**		**Feasibility**
	Treatments			Monitoring and Control [a]	Direct value	Option value	Plant capacity
	Effluent quality	Primary sedimentation T	Filtration sediments	€/m^3			PE
Hypothesis I	T1	15 °C		no apply	0.21	no apply	none
		20 °C		no apply	0.21	no apply	≥175,000
	T2	15 °C	with	no apply	0.21	no apply	≥100,000
			without	no apply	0.21	no apply	≥5000
Hypothesis II	**Preserving (1.7–2.2 dS/m)**						
	T1	15 °C		0.02	0.02	0.22	≥250,000
		20 °C		0.02	0.02	0.22	≥100,000
	T2	15 °C	with	0.02	0.02	0.22	≥30,000
			without	0.02	0.02	0.22	≥5000
	Restoring (<1.6 dS/m)						
	T1	15 °C		0.02	0.03	0.19	none
		20 °C		0.02	0.03	0.19	≥110,000
	T2	15 °C	with	0.02	0.03	0.19	≥40,000
			without	0.02	0.03	0.19	≥5000

Note: [a] Calculated as 8% of benefits obtained; Source: our elaboration.

The economic feasibility of reusing wastewater is primarily affected by the quality of the incoming effluent, with higher costs for lower quality effluent. The sedimentation temperature has less of an effect on the treatment cost. However, Puglia's climate could be beneficial because irrigation occurs during the summer, and higher temperatures are more convenient for wastewater reuse in agriculture.

While the filtration process seems to be highly relevant in the case of Hypothesis I, it has less influence when reclaimed wastewater is complementary to groundwater (i.e., Hypothesis II). Nevertheless, to provide farmers with on-farm pressurized irrigation water services, filtration could turn out to be more costly than advised. Although the benefits are quite steady, ranging from 0.20 to 0.22 €/m^3, the results for Hypothesis II show much lower costs than those for Hypothesis I. This is primarily due to the scale effects and the higher usability coefficient, which in turn reduce the unit operational cost of treatment.

5. Discussion and Concluding Remarks

The average treatment cost for agricultural wastewater reuse in Puglia is in line with that recorded in [19] for the case study of the Segura River Basin in southeastern Spain, which ranges from 0.16 to 0.26 €/m^3. However, both analyses only calculate the treatment cost at the plant gate, excluding the necessary costs for delivering the reclaimed water. Assuming that the irrigation service characteristics, performance and costs (financial, running and maintenance costs) of directly treated wastewater reuse for irrigation are similar to those of CBC, operating in the province of Foggia, the running costs of supply (i.e., transport and on-demand water delivery at the farm gate) would be at least 0.14 €/m^3. Where necessary, the financial cost of new infrastructure for direct wastewater reuse should also be considered.

Nevertheless, Alcon et al. [19] did not account for the cost of policy enforcement, assuming that wastewater suitable for use in agriculture is an efficient way to reduce the pressure on the resource. Moreover, instead of assessing the value of irrigation water usage per farmer, they actually estimated the non-use economic benefits of reclaimed wastewater per household (on average 0.31 €/m^3), i.e., the willingness to pay for increasing the quality of treated wastewater used in the replenishment of rivers.

Birol et al. [21] carried out a more rigorous assessment of the use and non-use economic benefits that may arise from wastewater treatment. According to their framework, farmers derive mainly direct use and option value from reclaimed wastewater, while the non-use value arising from conservation of the local environment benefits residents. Although they reported the monetary value in Cyprus pounds, the main finding indicates that residents derive significantly more benefits from wastewater treatment than farmers.

In this research, the use and option value that farmers may derive from reclaimed wastewater reuse ranges from 0.20 to 0.22 €/m^3, which is in line with the figures reported by Birol et al. [21], and thus less than those reported by Alcon et al. [19] for the non-use economic benefits of households.

With reference to Hypothesis II, the option value may heavily depend on the location and the characteristics of the farm considered. Generally, salt intrusion occurs close to the shoreline where the option value is expected to be higher. Thus, Hypothesis II should be evaluated against the local context, taking the coastal municipalities as the target. In fact, the share of reclaimed wastewater potentially available from coastal municipalities ranges from 14% in the province of Foggia to 88% in the province of Taranto, with an average value of about 55% in Puglia.

This work represents a first attempt to introduce an improved economic analysis to enhance both the community acceptance of wastewater reuse and the regional planning of public investment [44]. It should be noted that other important long-term environmental benefits, such as the expected increase in the quality of coastal sea water, were not included in the economic evaluation. The preservation of the aquatic marine environment and the beneficial impact on the regional economy (i.e., the tourist sector) is strictly related to the quality of bathing water.

With respect to the research questions, we have shown that the development of a regional case study is feasible, based on the fact that large areas such as Puglia already provide a homogenous background in terms of technological capacity and the possibility of upgrading to reuse requirements. Moreover, the comparison of costs and benefits proposed in this study could be considered as a reference methodological framework, which could be applied in different areas of the world characterized by a similar homogeneity of wastewater treatment standards and significant irrigation water demand.

We believe that this study's regional perspective provides a scientific contribution that should facilitate the comprehensive evaluation of costs and benefits. The evaluation can be extended to specific areas (and specific plant sizes, starting with those close to the identified break-even points) of the region, with the aim to find the optimal match between the capability of waste water plants and potential agricultural exploitation of this important unconventional water resource.

Supplementary Materials: The following are available online at www.mdpi.com/2073-4441/9/3/175/s1, Table S1: Procedure and amounts used for the evaluation of costs.

Author Contributions: Stefania Arborea, Vito Iacobellis and A. Ferruccio Piccinni conceived the economic appraisal of costs. Giacomo Giannoccaro and Bernardo C. de Gennaro conceived the economic appraisal of benefits. All authors made an equivalent contribution to the paper.

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