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Technical–Economic Evaluation of Water Reuse at the WWTP El Salitre (Bogotá, Colombia): Example of Circular Economy

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Abstract: Water resource management should be conducted from a multidisciplinary perspective. In this sense, the objective of this work is to analyze, from the perspective of the circular economy, the technical–economic feasibility of implementing different alternatives for the regeneration of wastewater for its subsequent reuse in industrial and sports companies located in Bogotá, Colombia. The development of the methodology is carried out through the method of economic cost–benefit analysis (ACB) and the technique of net present value (NPV). These methodologies facilitate decision making based on the economic feasibility of recovering the initial investment costs and the operating costs during the useful life of the WWTP. Establishing the cost and price of reclaimed water is essential to the efficient management of water resources; so far, the studies carried out only focus on the economic viability of the internal costs of the system, while the private impacts and the externalities are excluded and relegated to unsubstantiated statements about the advantages of water reuse. The economic feasibility incorporating the analysis of externalities presents a total profit that ranges between 6.52 EUR/m^3 for the industrial sector and 2503 EUR/m^3 for the irrigation of golf courses. This analysis demonstrates the technical and economic feasibility of carrying out a circular economy where the water already used returns as a new source of supply.

Keywords: circular economy; externalities; opportunity costs; reuse of treated wastewater; supply and demand of reclaimed water

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1. Introduction

The "El Salitre" treatment plant is in the city of Bogotá, and it is the one in charge of treating the wastewater from the north of the town, with a current load capacity equivalent to 2 million people. The WWTP begins with a pretreatment followed by a primary treatment of settling tanks that are subsequently dumped into the Bogotá River. Due to the scarcity of water that is occurring, and the pollution generated by the bodies of water, a proposal is made that allows decisions to be made for a process of efficient regeneration and reuse of water. Resolution 1096 of 2000 of the Republic of Colombia emerged as a mandatory regulatory instrument within the territory to provide treatment to wastewater and include it again for reuse. The purpose of this study is to analyze technically and economically the feasibility of implementing an alternative that allows the recovery of the costs of water regeneration and reuse, obtaining private economic profit from the commercialization of this resource. In addition, the evaluation allows the analysis and evaluation of the externalities of the system, such as the decrease in contamination generated by surface water bodies.

The companies selected to supply them with reclaimed water are characterized by having processes with high water consumption and their proximity to the WWTP "El Salitre".

Considering this framework, the marginal costs of producing reclaimed water versus obtaining it from a conventional source and its total profits are established.

1.1. Wastewater Treatment and Reuse

Currently, the "El Salitre" treatment plant has a process that begins with a pre-treatment that allows the removal of those bulky and fine solids as well as removing sand, fats, and oils; this is organized so that it does not affect the other subsequent processes. The primary treatment is a sedimentation process that removes up to 40% of DBO_5 and 60% of total suspended solids (TSS). With this process, the effluent obtained is still of low quality to be reused in the different potential uses that exist. For this reason, the proposal is to analyze the use of a secondary treatment that involves a biological treatment process, either (1) activated sludge or (2) trickling filters; in both cases, these processes are accompanied by a settler. The secondary treatment achieves up to 95% removal of DBO_5 and suspended solids. To increase the quality of the regenerated water, two tertiary treatments are proposed through disinfection: (1) disinfection via chlorine or (2) UV radiation.

1.2. The Circular Economy as a Solution to the Problem of Scarcity

The existence of water as a non-renewable resource opens the door to the development of different techniques that make it possible to extend the useful life of this resource; even though water is a basic necessity for all living beings, it is wasted and contaminated indiscriminately, due to the industrial, commercial, agricultural, and residential activities carried out by man [1]. Many countries are seeing the need to adopt new strategies that allow them to make posthumous use of wastewater, both domestic and industrial, and studies have shown that the reuse of this is one of the most economical and efficient alternatives [2]. This reuse is essential for those areas that are arid, semi-arid, or that simply do not have a large quantity of the water resource. In the same way, it manages to solve pollution problems and allows an increase in the availability of a resource without the need to over-exploit the conventional sources (surface or underground waters).

The reclaiming of treated wastewater should be considered as a new source of unconventional resources, whose management must be included in the comprehensive planning of water resources, considering economic, social, and environmental issues [3,4]. Reclaimed water can be used in traditional processes that do not require high quality, releasing volumes of better quality for other and more demanding uses [5].

Currently, many cities are presenting limitations on the use of drinking water, which is why they have chosen to use systems that allow the reuse of wastewater that is subjected to different types of processes, which adapt its quality depending on what it will be used for. The circular economy concept is related to the efficient use of natural resources, thus seeking to develop two fundamental aspects: smart growth, which becomes inclusive and sustainable economically, socially, and environmentally. In this way, it is achieved that the behavior of exploitation and use of water is not linear; on the contrary, the life cycle is closed, making it a constant resource and maintaining it as long as possible [6].

The behavior of the circular economy revolves around the relationship that exists between the reclaimed water market and potential end users. This is based on the promotion of sustainable practices and the efficient use that should be made of water resources. This type of economic model not only ensures that the economy grows but at the same time allows for a reduction in the indiscriminate exploitation of water basins and aquifers, for which reason a linear model that generates pollution and does not allow for a fulfilling helpful life is not followed for this resource [7]. The transition that is made from the linear to the circular model is to encourage the most efficient use of water innovation, with economic incentives for those who could be potential end users; likewise, it improves the capacity of an economy to manage the demands of the growing imbalance between the supply and demand of water [8].

1.3. Economic Aspects of the Circular Model

From the economic perspective of applying the concept of circular economy, the reuse of wastewater is presented as a "win-to-win" relationship [9,10]. The specific purpose of the circular economy is to create a behavior that closes the cycles of the resources and extends their useful life by adapting their quality for future use. When talking about reuse, a sustainable alternative is provided to avoid overexploitation of watersheds or aquifers; unfortunately, as these resources are cheap, society will continue to overexploit the resource, causing constant waste without foreseeing it for the future. The fact that water is consecrated as a vital right implies that it is often free, or the price paid is very little; this is questioned, as there are more and more economic charges associated with exploitation. Therefore the economic convenience is reflected in the investment of infrastructure for regeneration plants. This implies evaluating associated costs incurred for investment, operation, and maintenance as well as the construction of networks for distribution to different end users [11]. Once these costs are available, the minimum sale price of reclaimed water must be established, which must guarantee the recovery of the costs incurred and generate an economic profit. Generally, the costs of wastewater regeneration vary depending on the final use, whether for potable use or not, as well as whether it includes aspects of quality, supply, and quantity requirements [12,13]. Generally, purchasing reclaimed water is better for potential end users since they are not only encouraged by discounts on the rates they currently pay, but they also benefit from a continuous supply due to the amount of water released.

Water and wastewater management is one of the biggest challenges for the CE as many kinds of industries depend on water [14], and limited access to clean water resources can limit both production capacity and profits.

2. Materials and Methods

2.1. Definition of Scope Study

Table 1 shows the main characteristics of the city of Bogotá. Currently, economic activities represent 23.6% of the primary sector, secondary 40%, and tertiary 36.3%. It is important to note that, in Bogotá, the impact on the consumption of water resources by industry is quite high, and agriculture is the same. Therefore, the reclaimed water supply will be focused on this area.

Table 1. General aspects of Bogotá. (Own elaboration from the cited sources.)

General Aspects of Bogotá	Amount	Units
Urban area [1]	307	km^2
Territorial extension [1]	1776	km^2
Population [1]	8,080,734	inhabitants
Land use [1]	Agricultural: 2320	ha
	Ranch: 1684	ha
	Industrial: 2980	ha
Drinking water network coverage [2]	97.5	%
Sewerage network coverage [2]	90.2	%
Plants available for wastewater treatment [2]	1	

Note: [1] [15]; [2] [16].

Table 2 stipulates the water flows demanded and the alternatives of the possible users that would make the reuse of the reclaimed water, always starting from the quality characteristics stipulated by the Colombian legal framework.

Table 2. Alternatives for companies to reuse treated water. (Own elaboration from the cited sources.)

Wastewater Treatment Plant	Effluent Flow Rate	Alternatives	Reuse	End User	Estimated Consumption
Wastewater treatment plant "El Salitre"	118,890,720 m^3/year (3.77 m^3/s)	1	Recreational	Golf club and park La Florida [1]	18,023 (m^3/year)–43 (m^3/day)
		2	Industrial	Papeles primavera (paper and school supplies company) [2]	21,250,000 (m^3/year)–58,219 (m^3/day)
		3	Industrial	Sellopack (plastics production company) [3]	10,489,600 (m^3/year)–28,740 (m^3/day)
		4	Industrial	Licorera Cundinamarca [4]	3,488,040 (m^3/year)–9689 (m^3/day)

Note: [1] [17]; [2] [18]; [3] [19]; and [4] [20].

The wastewater generated in the city of Bogotá is currently treated in a primary treatment system within the "El Salitre" plant (currently under expansion and will begin operations in mid-2021); from this effluent, a proposal of different alternatives that are adapted to the already existing infrastructure was developed. The criteria stipulated to be able to use reclaimed water are established by Resolution 1207/2014 of the Colombian government [21]. The exclusive use of reclaimed water can only be used for agricultural, industrial, or recreational use. Likewise, it starts from the guidelines recommended by the World Health Organization [22], demanding the elimination of any pathogen that may directly or indirectly harm human beings. Table 3 shows in detail the information previously mentioned.

Table 3. Quality criteria for reuse alternatives. Source: [21].

Effluent Water Quality						
Parameter	**Unit of Measure**	**Quality Criterion for Reuse**				
			Industrial			
		Agriculture (Irrigation)	**Heat Exchange in Cooling Towers and Boilers**	**Discharge of Sanitary Equipment**	**Mechanical Cleaning of Roads and Irrigation of Roads to Control Particulate Matter**	**Firefighting Network Systems**
pH	Dimensionless	6.0–9.0	6.0–9.0	6.0–9.0	6.0–9.0	6.0–9.0
Thermo-tolerant coliforms	NMP/100 mL	1.0	1.0	1.0	1.0	1.0
Fecal Enterococci	NMP/100 mL	1.0	-	-	-	-
Helminths parasites in humans	eggs of larvae/L	1.0	0.1	1.0	1.0	0.1
Protozoa human parasites	cyst/L	1.0	0	1.0	1.0	1.0
Salmonella sp	NMP/100 mL	1.0	1.0	1.0	1.0	1.0
BOD_5	mg/L	0	1.0	1.0	1.0	1.0
Total phenols	mg/L	1.5	-	-	-	-
Free cyanide	mg CN/L	0.2	-	-	-	-
Chloride	mg Cl/L	300	-	-	-	-
Sulphate	mg SO_4/L	500	-	-	-	-
Mercury	mg Hg/L	0.002	0.001	-	0.001	-

Table 3. *Cont.*

Effluent Water Quality						
Parameter	**Unit of Measure**	**Quality Criterion for Reuse**				
			Industrial			
		Agriculture (Irrigation)	**Heat Exchange in Cooling Towers and Boilers**	**Discharge of Sanitary Equipment**	**Mechanical Cleaning of Roads and Irrigation of Roads to Control Particulate Matter**	**Firefighting Network Systems**
Floating material	present or absent	Total absence	Total absence	-	-	-
Suspended solids	mg/L	Total absence	Total absence	-	-	-
Oil and fats	mg/L	Total absence	Total absence	-	-	-
Total residual chlorine (with at least 30 min of contact)	$mgCl_2/L$	Less than 1	-	-	-	-
Nitrate (NO_3^-, N)	mg NO_3^-/L	5	-	-	-	-

The expansion and optimization of the Wastewater Treatment Plant, PTAR Salitre Phase II, includes the following process: activated sludge followed by a secondary decanter to increase the efficiency of discharge quality; with these new treatment units, an approximate elimination will be achieved of SS (60–99%), BOD (60–99%), Total Coliforms (60–99%), and Nutrients (10–55%). Regarding tertiary treatment (Asano, 2007), a filtration process with disinfection is proposed, and this allows a high quality of the final effluent, achieving removal of SS (>99%), BOD (>99%), Total Coliforms (>99.9%), and Nutrients (>90%). Through interviews and consultations with experts [23–25] the costs incurred for construction, operation, and maintenance were established. On the other hand, the externalities that could impact the project were identified, either positive (income or benefit) or negative (expense or disadvantage), and likewise, the opportunity cost is included, which refers to the cost generated by investing the funds destined for the plant in another activity that generates greater profitability. In this case, an investment analysis was made of the total cost of carrying out the project in the purchase of government bonds, which raises a gain of 6.72% over 10 years.

2.2. Economic Analysis

The economic analysis starts with establishing, analyzing, quantifying, and monetarily evaluating the impacts of the project for a given area. This analysis is because the cost that is being incurred is real, which means the project manages to make the treatment of wastewater at a minimum cost. Said identification starts from those already existing impacts in the "El Salitre" treatment plant and those derived from carrying out the treatment based on the advantages and costs of investment, operation, and maintenance. This also allows for the comparison of the marginal costs of producing reclaimed water versus the cost of obtaining a quantity of water from another source of supply. The valuation methodology analyzes the economic behavior of the treatment plant, this includes all the private costs and profits that are measurable in financial terms; therefore, the total profits are maximized, using private profits as a starting point, taking into account positive or negative externalities and opportunity costs [26,27]. The objective function is determined as follows (see Equation (1)):

$$P_T = \sum_{n=0}^{n}[(RAV_n * SV_n) - (IC_n + COM_n + FC_n + T_n) + (PE_n - NE_n) - OC_n] \quad (1)$$

where P_T = Total Profit; RAV = Annual Volume of Regenerated Water; SV = Sale Price of reclaimed water; IC = Investment Cost; FC = Financial Costs; T = Tax; PE = Positive Externalities; NE = Negative Externalities; OC = Opportunity Costs; COM = Cost of Operation and Maintenance; and n = Year.

2.3. Aggregation of Costs and Incomes

The private costs obtained in Tables 4 and 5 refer to the costs of each of the processes where the selection was based on a cost-efficiency analysis, and from this analysis, the selected technology was activated sludge followed by a tertiary treatment of disinfection and UV rays due to its high level of efficiency in pollutant removal.

Table 4. Investment, operation, maintenance, and water regeneration costs per m^3 for selected water line options.

Investment, Operation, Maintenance, and Regeneration Costs of Selected Options for the Water Line						
Design for Medium Flow (4 m^3/s) and Peak Flow (9.9 m^3/s)		**Investment Cost**	**Operation and Maintenance Costs (EUR/Month)**	**Operation and Maintenance Costs (EUR/Year)**	**Cost Obtaining Reference**	**Regeneration Cost (MSP EUR/m^3)**
		Civil Works and Equipment (EUR)				
Preliminary	Coarse and fine grinding	77,019,207 [1]*	169,281 [1]*	2,031,378	Bogotá water, sewerage, and cleanliness (2018). Monthly operation report	0.1028
	De-sanding and degreasing					
Primary	Sedimentator or primary decanter					
Secondary	Activated sludge—aerobic + Secondary settlers.	462,348,180 [2]*	6,472,873 [2]*	77,674,487	Database "CONSTRUDATA" ciudad de Bogotá, Escuela Colombiana de ingenieros Julio Garavito	1.1195
Tertiary	1. Filtration 2. Disinfection	4,740,227 [3]*	7193 [3]*	86,323	Lexington, Massachusetts (2018), wastewater treatment performance and cost data.	0.0058
Total cost of water treatment						1.2283

Notes: [1] [28]; [2] [15]; and [3] [29,30]. * Update of data based on statistical estimates (2022): update of capitals = (N × (CPI) + 1).

Table 5. Final cost of sludge treatment (own elaboration).

Investment Cost, Maintenance, Operation, and Final Treatment of Sludge					
Treatment	**Investment Cost**	**Operation and Maintenance Costs (EUR/Month)**	**Cost (EUR/Year)**	**Cost Obtaining Reference**	**Cost of Treatment (MSP EUR/m^3)**
	Civil Works and Equipment (EUR)				
Initial thickening	29,518,581 [1]*	7369	88,430	Bogotá water, sewerage, and cleanliness (2018). Monthly operation report	0.0321
Anaerobic digester (primary sludge)	4,727,168 [1]*	10,620	127,447		0.0062
Dehydration band treatment	26,511,451 [1]*	15,971	191,659		0.0315
Thermal drying treatment (rotating drum)	80,498,393 [2]*	4655	55,868	PESA company price (2018)	0.0906
Total cost of sludge treatment					0.1604

Notes: [1] [28] and [2] [29,30]. * Update of data based on statistical estimates (2022): update of capitals = (N × (CPI) + 1).

The private costs obtained in Tables 4 and 5 refer to the costs of each of the processes. The selection was based on a cost-efficiency analysis, and from this analysis, the selected technology was activated sludge followed by a tertiary treatment of disinfection and UV rays due to its high level of efficiency in pollutant removal.

With the information presented in Tables 4 and 5, the minimum sale price (MSP) of reclaimed water is calculated, and this price guarantees the recovery of the expected costs and profits, and this investment must be made under the net present value criterion, which indicates the profitability of the project. Therefore, the (MSP) is calculated from the net cash flow (Equation (2)), when the net present value is equal to zero (see Equation (3)).

$$\mathrm{NCF} = \mathrm{MSP{-}C{-}T} \tag{2}$$

where NCF = Net cash flow; C = Costs; MSP = Minimum sale price; and T = Tax.

$$\mathrm{NPV} = -\mathrm{IC} + \sum_{0}^{n} \frac{\mathrm{NCF_n}}{(1+\mathrm{i})^{\mathrm{n}}} = 0 \tag{3}$$

where NPV = Net Present Value; i = discount rate; IC = Investment Cost; n = annual discount; and FNE = net cash flow.

The following assumptions for economic analysis are made for the technical and fiscal characteristics:

- Project lifespan: 20 years;
- Tax depression 5.5%;
- There is a 19% tax lien;
- Inflation and uncertainty are not considered since the analysis is for one year (it is a static analysis);
- Opportunity costs are calculated from interest rates of 6.72% on state bonds.

The construction of networks for the distribution of reclaimed water to end users depends on the distance from the treatment plant and is stipulated in Table 6.

Table 6. Total investment cost in distribution networks and distribution cost of end users of reclaimed water.

Company	Supply (m^3/Year)	Driving Distance (km)	Total Investment in Distribution (EUR)	Distribution (EUR/m^3)
Sellopack [1]	10,490,100	7.78	341,736	0.0336
Papeles primavera [2]	21,249,935	9.68	425,194	0.0200
Licorera Cundinamarca [3]	3,536,485	3.06	134,410	0.0380
La Florida Golf Course [4]	15,695	3.42	150,223	1.0586
Total			1,051,564	1.1483

Note: [1] [19]; [2] [18]; [3] [20]; and [4] [17].

In Table 7, the results of the total costs obtained for each of the companies are presented. As can be seen, in the case of Sellopack, a distribution cost of 0.0336 EUR/m^3, is added to the minimum price of sale of 1.3886 EUR/m^3 (this cost is the result of the sum of the MSP for water treatment, 1.2282 EUR/m^3, and the MSP for sludge treatment, 0.1604 EUR/m^3), meaning that the treatment and distribution of reclaimed water for this company is at 1.3922 EUR/m^3; currently, they pay 6.39 EUR/m^3 for conventional supply.

However, with bilateral agreements, it would be possible to establish a discount equivalent to 15% on the price they currently pay; this indicates that they have to pay 5.43 EUR/m^3, which is reflected in Table 8.

Table 7. Total cost of producing and distributing reclaimed water.

Company	Distribution (EUR/m^3)	Production (EUR/m^3)	Total Cost of Water (EUR/m^3)
Sellopack	0.0336	1.3886	1.3922
Papeles primavera	0.0200	1.3886	1.3908
Licorera Cundinamarca	0.0380	1.3886	1.3928
La Florida Golf Course	1.0586	1.3886	2.4463

Table 8. Sale price of reclaimed water with a 15% discount.

Company	Conventional Source Water Price (EUR/m^3)	Sale Price of Regenerated Water (EUR/m^3)
Sellopack	6.39 [1]	5.43
Papeles primavera	6.39 [2]	5.43
Licorera Cundinamarca	6.39 [3]	5.43
La Florida Golf Course	4.99 [4]	4.15

Note: [1] [19]; [2] [18]; [3] [20]; and [4] [17].

Table 9 establishes the private profits generated by the wastewater regeneration process; these are based not only on the profit obtained by end users but also by the company providing the service, "Acueducto de Bogotá".

Table 9. Private profits.

Companies That Buy Reclaimed Water				Acueducto de Bogotá	
Company	Supply (Mm^3/Year)	Profit (EUR/m^3)	Profit (MEUR/Year)	Profit (EUR/m^3)	Profit (MEUR/Year)
Sellopack	10.49	0.96	10.0	4.04	42.3
Papeles primavera	21.25	0.96	20.3	4.04	85.8
Licorera Cundinamarca	3.5	0.96	3.3	4.04	14.2
La Florida Golf Course	0.0015	2.24	0.035	1.70	0.026

On the other hand, there are the costs of private profits that are not only generated for the provider company Acueducto de Bogotá but also for end users that not only have a discount percentage but also positions them as environmental and sustainable companies.

2.4. Total Profit

Now, from these costs, the total profit is calculated, which is also based on generating a maximization based on private profits, the economic valuation of negative and positive externalities, and the opportunity cost (Equation (4)). This allows us to validate the economic decision making for the regeneration of residual water and its subsequent reuse, and this decision is given by the entity in charge, which is Acueducto de Bogotá.

$$P_T = P_P + P_E – OC \tag{4}$$

where P_T = Total Profit (Total Income - Total Costs); P_P = Private Profit (Private income − Private costs); P_E = Profit from Externalities (Income externalities − Costs externalities); and OC = Opportunity Costs.

3. Results and Discussion

As can be seen in Table 10, the quantification and assessment of the impacts generated by the implementation of the proposal allow us to determine that the total profit obtained by each of the companies varies in favor of distance factors and costs for the sale of m^3 of reclaimed water for each of the established sectors. In the four companies, the feasibility of implementation is determined due to the recovery of the investment and exploitation and maintenance costs, but it also shows the greatest difference between the probable maximum income and the minimum sale price. By the above, the sectors that generate the greatest profit are those with industrial characteristics, with a profit oscillating among 6.52 EUR/m^3 of reclaimed and distributed water, in the case of the agriculture sector a lower profit is presented due to being subsidized by the state.

Table 10. Analysis of the economic quantification of the externalities of the project.

Impact Group	Impacts Involved	References in the Literature on the Assessment of This Impact	Sellopack		Papeles Primavera		Licorera Cundinamarca		La Florida Golf Course	
			Quantification		Quantification		Quantification		Quantification	
			Positive	Negative	Positive	Negative	Positive	Negative	Positive	Negative
			EUR/m^3	EUR/m^3	EUR/m^3	EUR/m^3	EUR/m^3	EUR/m^3	EUR/m^3	EUR/m^3
Hydraulic infrastructure	Wastewater treatment (EUR/year)	[31]		1.3922 [1]		1.3908 [1]		1.3928 [1]		2.4463 [1]
	Regeneration and reuse of wastewater	[32]								
	Networks adaptation for the transport of reclaimed water	[33]		0.0336		0.0200		0.0380		1.0586
	Opportunity cost of investment	[34]		0.00480		0.00480		0.00480		0.00480
Conditioning and reuse of by-products	Sludges (biosolids)	[35]	0.045		0.045		0.045		0.045	
	Energy and biogas		N.C.		N.C.		N.C.		N.C.	
Use of resource	Quantities to supply	[36]	5.43		5.43		5.43		4.15	
	Supply guarantees		N.C.		N.C.		N.C.		N.C.	
Environment	Environmental improvement of the river	[37]	2.49		2.49		2.49		2.49	
	Atmospheric pollution CO_2 emissions	[38]		0.016 [2]		0.016 [2]		0.016 [2]		0.016 [2]
Total EUR			7.956	1.446	7.965	1.443	7.965	1.451	6.685	3.525
Total Profit			6.518		6.532		6.514		3.159	

Note: [1] Tables 5–7; [2] [39].

The results obtained allow us to open the change path from a linear economy based on extraction, adaptation, distribution, use, and discharge to a circular economy that materializes in repeatedly using water, managing to establish the dynamics of the natural cycle. This achieves a balance between the efficacy of the different treatment systems, their economic viability, and their impact as sustainable behavior on a large scale.

As can be seen in Table 9, it can be stated that the profits represent a gain of approximately 4.04 EUR/m^3 for the industrial sector and 1.70 EUR/m^3 for the sports sector. This indicates that not only the cost incurred by regeneration is recovered but also that profits were obtained. The four selected companies are feasible as end users, obtaining a maximum profit for them, ranging from 0.96 EUR/m^3 and 2.24 EUR/m^3 for the irrigation of golf courses. Despite not having quantified all externalities due to the lack of information, the model shows that since they are only positive externalities, their calculation would only increase the profitability of the proposed project, so the viability will not be affected. The model provides an appropriate tool for the planning and management of water resources.

4. Conclusions

The water sector in Bogotá, Colombia is in a transitional phase with unique opportunities for water reuse to be implemented on a large scale as a sustainable practice within a framework of integrated water management. Water is crucial for economic development since it interacts with all the sectors. The circular economy has become a fundamental model for environmental management, especially in the water sector. The main approach is based mainly on the fact that water reuse can spread the water already used, increasing the availability of water resources. Consequently, reclaimed water can be used in traditional processes that do not require high quality, releasing volumes of better quality for other and more demanding uses [5,40].

The main contribution made by this study is the analysis of the economic viability of the proposed alternative, generating lines of support for decision making. This described methodology makes it possible to ensure that the investment of costs allows for obtaining a maximization of total profits. Likewise, a series of externalities are evaluated to be able to identify, quantify, and value economically their impact on implementation.

The minimum sale price is determined under the net present value (NPV) criterion; the selection of the four companies presents a maximization of total profit for the industrial sector of 5.43 EUR/m^3 and companies in the special sector of 4.15 EUR/m^3. For this reason, the proposed alternative and the selection of possible end users show the feasibility of the implementation. For these companies, the economic profit will be presented at a low price for reclaimed water with a constant supply instead of paying for the conventional source, which is more expensive and is subjected to supply cuts due to dry seasons. This alternative must follow the quality standards that are legally required to guarantee the safety of the reuse of reclaimed water implemented in a circular economy context; in addition, this work provides a scientific contribution that should facilitate a comprehensive evaluation of costs and benefits.

For future research, it is recommended to address limitations that were not taken into account in the development of this methodology, such as the analysis of the selected technologies and determining their reliability, performance, robustness, and resilience; in the economic part, it is recommended to evaluate the price difference in the price of fresh water vs. reclaimed water, since the difference is not notable, making treated and reclaimed water not competitive enough; and in the social part, it is necessary to face challenges for public acceptance of the use of treated and reclaimed water in connection with the industrial, agricultural, or recreational sectors, thus achieving a successful exchange of resources.

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