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Feasibility Study of Water Reclamation Projects in Industrial Parks Incorporating Environmental Benefits: A Case Study in Chonburi, Thailand

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Abstract: Financial feasibility is usually a concern in water reclamation projects. Aside from internal benefits, water reclamation in industrial parks delivers health and environmental benefits not normally considered in cost–benefit analyses (CBA). This study investigated the influence of environmental benefits on the feasibility of water reclamation projects with flow rate scenarios in accordance with industrial parks in Chonburi, Thailand. CBAs of water reclamation plants for industrial water supply, consisting of ultrafiltration (UF) and reverse osmosis (RO), with flow rates of 5200, 10,000, 15,000, and 25,000 m^3/day and discount rates of 3%, 5%, 7%, 9% and 11% were conducted. Considering only the direct costs and benefits, none of the projects were financially feasible. However, when the environmental benefits were included, the projects became profitable in all cases except those with a flow rate of 5200 m^3/day and discount rates of 5%, 7%, 9%, and 11% and those with flow rates of 10,000 and 25,000 m^3/day and an 11% discount rate. Further, CBAs of water reclamation projects in industrial parks for irrigation were conducted with post-treatment processes consisting of sand filtration and chlorine disinfection for flow rates of 240, 480, 2400, 3600, and 4800 m^3/day. The projects are profitable, regardless of environmental benefits.

Keywords: cost–benefit analysis; industrial water reuse; environmental benefit; irrigation

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1. Introduction

Industrialization, urbanization, and population growth have increased the demand for water worldwide, leading to water scarcity in many countries [1]. Interannual and intra-annual climate variability are becoming greater, resulting in higher fluctuations in the water supply. The observed changes in heavy precipitation, droughts, and tropical cyclones have strengthened since 2014 [2]. The provision of clean water and water use efficiency are part of the Sustainable Development Goals (SDGs) adopted by the United Nations in 2015 [3]. A circular economy is an economic framework that maximizes service using cyclical material flows, renewable energy sources, and cascading-type energy flows [4], and it is also reflected in SDG 12—responsible consumption and production [3]. "Wastewater" is an important component of the circular economy [5], and water reclamation and reuse are increasingly being integrated into water resource management, as they are expected to mitigate water scarcity worldwide and provide flexibility to respond to both short- and long-term water supply needs [6,7].

Industrial parks, particularly those located in water-stress areas, have high water demands that may compete with municipal and agricultural water demands, necessitating appropriate water reuse to conserve natural water resources and assure industrial park sustainable development [8]. Water reclamation has been shown to provide various benefits, including economic, environmental, health, and social benefits [9–17]. Apart from the direct benefits of reclaimed water, water reclamation can effectively lessen pollution emissions, provide nutrients as fertilizers, conserve freshwater resources, and offer recreational benefits [9,11,17,18]. According to a life cycle analysis (LCA) of water reuse in an industrial park is environmentally beneficial compared to the no-reuse scenario in most aspects, that is, marine aquatic toxicity, abiotic depletion, acidification, eutrophication, freshwater aquatic ecotoxicity, global warming, human toxicity, terrestrial ecotoxicity, and photochemical oxidation, with eutrophication and freshwater aquatic ecotoxicity potentials greatly depending on the pollutants discharged into the environment [19]. Moreover, water reclamation can potentially provide ecosystem service values, although research in this area is still limited [20,21].

However, water reclamation can be challenging due to social, technological, economic, and regulatory constraints [22]. Economic feasibility, along with public acceptance, is considered a key factor in the implementation of water reclamation projects [12,22], since high-cost advanced treatment technologies are usually required to ensure that reclaimed water is of high quality [23–25]. Despite its importance, public information on the economic feasibility of water reclamation projects in industrial parks is still limited [10]. Few studies have compared the costs of different water reuse options with those of the water supply options available in the areas under study [26,27]. Furthermore, there are still no studies that consider externalities, such as environmental and social costs/benefits, of water reclamation projects in industrial parks, although these issues have been suggested for inclusion in an economic analysis of water reclamation projects [28,29] and have been addressed in previous studies on the water reclamation of effluents from municipal wastewater treatment plants (WWTPs) [12–17]. The inclusion of externalities in cost–benefit analysis (CBA) can disclose the genuine value of water reclamation projects [13], which can be used to obtain governmental support for such initiatives. Further, although LCA can provide information on all environmental aspects of water reclamation projects, it cannot be coherently combined with an economic feasibility analysis in the decision-making process. The economic and environmental dimensions are still considered separately [27]. CBA, with the inclusion of externalities, is an emerging tool for merging the two dimensions in the decision-making process, which can ensure economic, environmental, and social sustainability [12].

Chonburi is a province in Thailand located in the Eastern Economic Corridor (EEC), initiated by the Thai government to promote industrial growth. Water scarcity in the EEC is predicted to affect all sectors in the next 20 years [30]. Thus, there is an urgent need to place water reuse in the EEC on the policy agenda. To increase internal water reuse in industrial parks, the Industrial Estate Authority, Thailand, issued regulations requiring the reuse of at least 15% of the water supply in industrial parks established after 2015. Based on our 2018 survey, Chonburi has a high percentage of internal water reuse in industrial parks, up to 70.5%, with most industrial parks in Chonburi mainly reclaiming water for two activities: (1) industrial water supply and (2) irrigation of plants and green areas [31]. Thus, Chonburi can serve as a model for internal water reuse in industrial parks, and its data are readily available for economic feasibility analyses. Such analyses will provide valuable information for other industrial parks in Thailand and other developing countries with similar industrial park types and socioeconomic statuses.

Therefore, the objectives of this study are (1) to evaluate the feasibility of water reclamation projects in industrial parks using CBA that incorporates both economic and environmental aspects, and (2) to examine the impact of environmental benefits on the feasibility of water reclamation projects in industrial parks under different scenarios (water reclamation activities, flow rates, and discount rates). This article is divided into four sections: introduction, methods, results and discussion, and conclusions. In the methods section, the background of Chonburi province is described, and the methodology of cost and benefit calculations and CBA are presented with an explanation of various water reclamation scenarios. The CBA of two water reclamation activities—that is, (1) for industrial water supply and (2) for irrigation of plants and green areas—are examined. We selected different flow rate scenarios in accordance with industrial parks in Chonburi, Thailand, which fall within the typical range for small-to-large industrial parks (Table S1). The discount rates used varied from 3% to 11%, covering those generally used for this type of project. The environmental benefits of water reclamation from not discharging pollutants into the environment were estimated using shadow prices for pollutants, which directly reflect the cost of damages if discharged to the environment. Net present values (NPVs), internal rates of return (IRRs), benefit–cost ratios (BCRs), and payback periods (PPs) were estimated and compared in cases with the inclusion and exclusion of environmental benefits. The results of the CBA are then presented in the results and discussion section, along with practical implications, recommendations for governmental support, and limitations and suggestions for future research. Lastly, all results and discussion are summarized in the conclusions.

Although the inclusion of externalities in the economic analysis of water reclamation has long been proposed [28,29], research in this area has been incomplete, particularly for water reclamation in industrial parks in developing countries. This study used the CBA framework with the inclusion of environmental benefits in real applications to examine the economic feasibility of water reclamation projects in industrial parks across a wide range of scenarios, utilizing data from industrial parks in Chonburi, Thailand, as a case study. Limitations and research gaps required for practical applications are also addressed. Moreover, shadow prices of pollutants were first applied to estimate the environmental benefits of water reclamation in industrial parks for not discharging them to the environment. The findings of this study can assist us to appreciate the true worth of water reclamation projects in industrial parks and to fully comprehend how environmental benefits affect the feasibility of water reclamation projects. Furthermore, they can serve as guidelines for the necessary governmental support that will substantially assist industrial parks in completing their initiatives. The CBA of different water reclamation scenarios can also help identify the most appropriate options under different circumstances.

2. Methods

2.1. Background of Water Reuse in Industrial Parks in Chonburi, Thailand

Chonburi Province is located in the eastern region of Thailand in the EEC, along with nearby provinces, that is, Rayong and Chachoengsao. Under the EEC initiated by the Thai government, the province is now set to become a major industrial center for Thailand's eastern region, with the port of Laem Chabang serving as a major commercial port. It is also a tourist attraction with a diverse and beautiful natural landscape. Chonburi's gross provincial product (GPP) was THB 1,030,949 million, equivalent to 6.3% of Thailand's gross domestic product (GDP) in 2018, making it the third-highest GPP in the country [32]. The economic structure of Chonburi Province in 2018 was divided into three sectors: industry (64.78%), agriculture (2.44%), and tourism and services (32.78%) [33].

Based on a study conducted by the Office of the National Water Resources [30], the water demand in Chonburi around 2017 was 469 million cubic meters (MCM), while in Rayong it was 494 MCM, and Chachoengsao recorded 1456 MCM. The major water use in Chonburi and Rayong is industrial water use, while Chachoengsao mainly uses water for irrigation. The study also projected that in the next 20 years, around 2037, the domestic and industrial water demand in the three provinces would increase from approximately 857 MCM to 1258 MCM.

Eight industrial parks are located in Chonburi, as shown in Figure 1, with 11 central WWTPs. Most factories in the industrial parks in Chonburi produce auto parts and electronic parts. According to our 2018 survey [31], which obtained secondary data from industrial parks in Chonburi, the flow rates of wastewater in the central WWTPs in the industrial parks in Chonburi varied from 226 to 12,704 m^3/day (Table S1), with a total flow rate of 51,119 m^3/day or 18,658,501 m^3 per year. The concentrations of pollutants in WWTP effluents, that is, biochemical oxygen demand (BOD), chemical oxygen demand

(COD), total Kjeldahl nitrogen (TKN), total phosphorus (TP), suspended solids (SS), total dissolved solids (TDS), and heavy metals, are shown in Table S2. A total of 70.5% of the wastewater was reused for various activities, that is, industrial water supply (49.7% of water reuse), irrigation of plants and green areas (21.1% of water reuse), power plant cooling water (28.7% of water reuse), and sale of reused water without post-treatment (0.5% of water reuse).

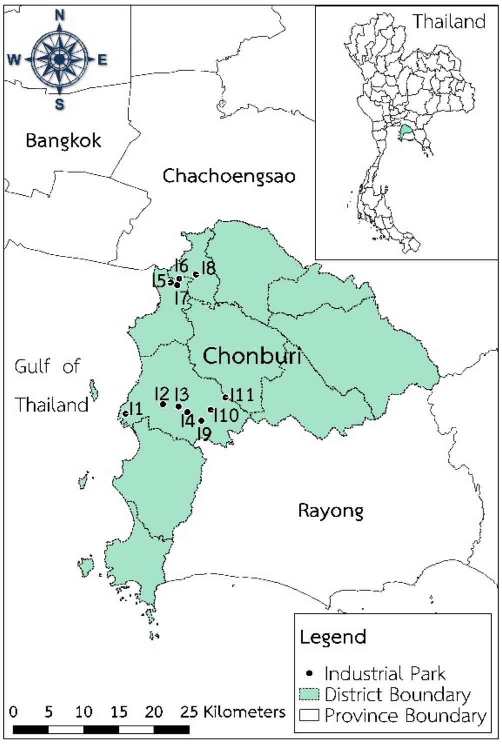

Figure 1. Locations of industrial parks in Chonburi Province, Thailand.

2.2. Scenarios of Water Reclamation Projects in Industrial Parks

In this study, we evaluate the economic feasibility of two types of water reclamation projects in industrial parks: (1) water reclamation projects for industrial water supply and (2) water reclamation projects for the irrigation of plants and green areas. These are the primary water reclamation activities in Chonburi's industrial parks, accounting for 70.8% of water reuse. Although reclaimed water used for power plant cooling accounted for 28.7% of total water reuse, Chonburi has only one industrial park with a power plant. The majority of industrial parks lack their own power plants. As a result, water reclamation for power plant cooling is uncommon in industrial parks.

For water reclamation projects for industrial water supply, we assumed that the system consisted of ultrafiltration (UF) and reverse osmosis (RO) units. This assumption is based on the actual systems that have been successfully constructed and operated in several industrial parks in Thailand. CBAs were conducted for different wastewater flow rates—5200, 10,000, 15,000, and 25,000 m^3/day—, covering typical flow rates in industrial parks in Chonburi that reclaim water for industrial water supply. RO permeate was assumed to be 75% of the influent. The assessment was conducted for cases that included and excluded externalities.

For water reclamation plants for the irrigation of plants and green areas in industrial parks, we assumed that the system consisted of sand filtration and chlorine disinfection. This system is considered appropriate and highly affordable in developing countries. CBAs were conducted for wastewater flow rates of 240, 480, 2400, 3600, and 4800 m^3/day. These flow rates were selected based on the reclaimed water for the irrigation of plants and green areas in industrial parks in Chonburi, which were typically less than 20% of wastewater flow rates, according to our 2018 survey [31], together with the highest maximum capacity of the central WWTPs in the industrial parks in Chonburi (24,000 m^3/d). Thus, the maximum flow rate selected was 4800 m^3/day, and the lower flow rates varied. This irrigation activity is assumed to have no negative environmental impact on the soil, and the volume is not too large to infiltrate groundwater and affect groundwater quality.

Notably, the flow rates chosen for these two water reclamation activities (industrial water supply and irrigation of plants and green areas) were not the same. The irrigation of plants and green areas was usually limited by the green areas available in industrial parks; thus, the flow rates were typically less than 20% of the WWTP effluent. By contrast, water reclamation for industrial water supply is not limited in this way.

2.3. Estimation of the Costs and Benefits of Water Reclamation Projects

For water reclamation projects for industrial water supply, the direct costs and benefits of these projects included construction costs, operation and maintenance costs, and revenues from the sale of reclaimed water. The information used for the estimation of direct costs and benefits is shown in Table 1.

Table 1. Information for estimating the direct costs and benefits of water reclamation projects for industrial water supply, consisting of ultrafiltration and reverse osmosis.

Direct Costs and Benefits	Wastewater Flow Rates (m^3/d)			
	5200	**10,000**	**15,000**	**25,000**
Volume of reclaimed water produced (m^3/d) (1)	3900	7500	11,250	18,750
Direct costs				
Construction costs (THB million) (2)	108.2	145	187	332
Operating and maintenance costs (million THB/year) (3)	37.96	73	109.5	182.5
Direct benefits				
Water prices (THB/m^3) (4)	26	26	26	26

(1) We assumed that the filtrate flow rates were 75% of the wastewater flow rates. (2) These are the actual construction costs of water reclamation plants in Thailand disclosed by industrial estates that used ultrafiltration and reverse osmosis systems, which included the costs of pipeline systems. (3) Ratanathamsakul et al. (2020) [34]. (4) This is the water price in an industrial estate (Industrial Estate Authority of Thailand).

For cases that included externalities, the environmental benefits of not discharging WWTP effluent into the river were included as positive externalities. The costs of environmental damage from pollutants in wastewater, such as nitrogen, phosphorus, SS, and COD, were estimated based on their average concentrations in the WWTP effluents of industrial parks in Chonburi in 2018 (Table S3). In the absence of recent information on the costs of environmental damage from water pollutants discharged into water bodies in Thailand, these values were derived from the shadow prices of pollutants discharged into a river in Spain (−16.353 EURO/kg N; −30.944 EURO/kg P; −0.005 EURO/kg SS; and −0.098 EURO/kg COD) in [35]. The shadow prices of pollutants were estimated from the associated costs of pollutant removal in the treatment process. When a water reclamation project exists, no pollutants are released. The shadow prices of pollutants, therefore, reflect environmental benefits that are positive externalities in the CBA. Equation (1) was then used to account for the exchange rates of the currencies and the difference in gross domestic product based on purchasing power parity (GDP (PPP)) per capita in Spain and Thailand, reflecting the difference in the ability to purchase goods and services per capita in the two countries [36]. The values of the money in 2020 were estimated using Equation (2).

$$CFR_{TH2010} = \frac{\text{GDP (PPP) per capita}_{TH2010}}{\text{GDP (PPP) per capita}_{SP2010}} \times E_{2010} \quad (1)$$

where

CFR_{TH2010} = Thailand's PPP conversion in 2010 (THB/EURO)

GDP (PPP) per capita $_{TH2010}$ = GDP (PPP) per capita of Thailand in 2010
= 13,195.36 USD [37]
GDP (PPP) per capita $_{SP2010}$ = GDP (PPP) per capita of Spain in 2010
= 31,593.85 USD [37]
E_{2010} = average exchange rate in 2010 = 42.4 THB/EURO [38]

$$\mathrm{FV} = \mathrm{PV}(1 + \mathrm{r})^{\mathrm{n}} \tag{2}$$

where

FV = future value of the investment of present value (PV) (the values in 2020)
PV = present value of an investment (the values in 2010)
r = 10-year average inflation rate (2010–2020), which is 1.42% [39]
n = number of compounding periods (10 years)

Regarding water reclamation plants for the irrigation of plants and green areas in industrial parks, the direct costs and benefits included construction costs, operation and maintenance costs, revenues from the sale of reclaimed water, and savings on fertilizer costs due to the nitrogen and phosphorus contents in reclaimed water. The information used for the estimation of direct costs and benefits is shown in Table 2. Indirect environmental benefits from not discharging WWTP effluents into rivers were estimated from the average pollutant concentrations in WWTP effluents together with their shadow prices [35] using Equations (1) and (2) in the same manner as that used for water reclamation projects for industrial water reuse.

Table 2. Information for estimating the direct costs and benefits of water reclamation projects for the irrigation of plants and green areas, consisting of sand filtration and chlorination.

Direct Costs and Benefits	**Wastewater Flow Rates (m^3/d)**				
	240	**480**	**2400**	**3600**	**4800**
Volume of reclaimed water produced (m^3/d) (1)	240	480	2400	3600	4800
Direct costs					
Construction costs (THB million) (2)	1.4	2	12	16	24
Pipeline system costs (THB million) (3)	0.505	0.87	2.795	2.795	5.21
Operating and maintenance costs (million THB/year) (4)	0.1971	0.3942	1.971	2.9565	3.942
Direct benefits					
Reclaimed water prices (THB/m^3) (5)	12	12	12	12	12
Nitrogen fertilizer price (6) (THB/kg)	11.5	11.5	11.5	11.5	11.5
Phosphorus fertilizer price (6) (THB/kg)	17.1	17.1	17.1	17.1	17.1

(1) We assumed no loss in the water reclamation systems. (2) The construction costs of sand filtration and chlorine contact tank units in water treatment plants are obtained from the Provincial Waterworks Authority of Thailand. (3) The costs of pipeline installation in Thailand are obtained from contractor companies under the assumption that the water distribution distance was 5 km. (4) Ratanathamsakul et al. (2020) [34]. (5) These are the reclaimed water (second grade water) prices disclosed by an industrial estate. (6) The fertilizer prices are from the Bureau of Agricultural Economic Research, Thailand.

2.4. Cost–Benefit Analysis of Water Reclamation Projects

CBA was used to analyze the economic feasibility associated with reclaimed wastewater projects in industrial parks with different flow rate scenarios. The analysis was completed by assessing various indicators: NPVs, IRRs, BCRs, and PPs [15,40]. The methodology flowchart of the CBA of water reclamation projects in industrial parks, including all of the scenarios conducted in this study, is illustrated in Figure 2.

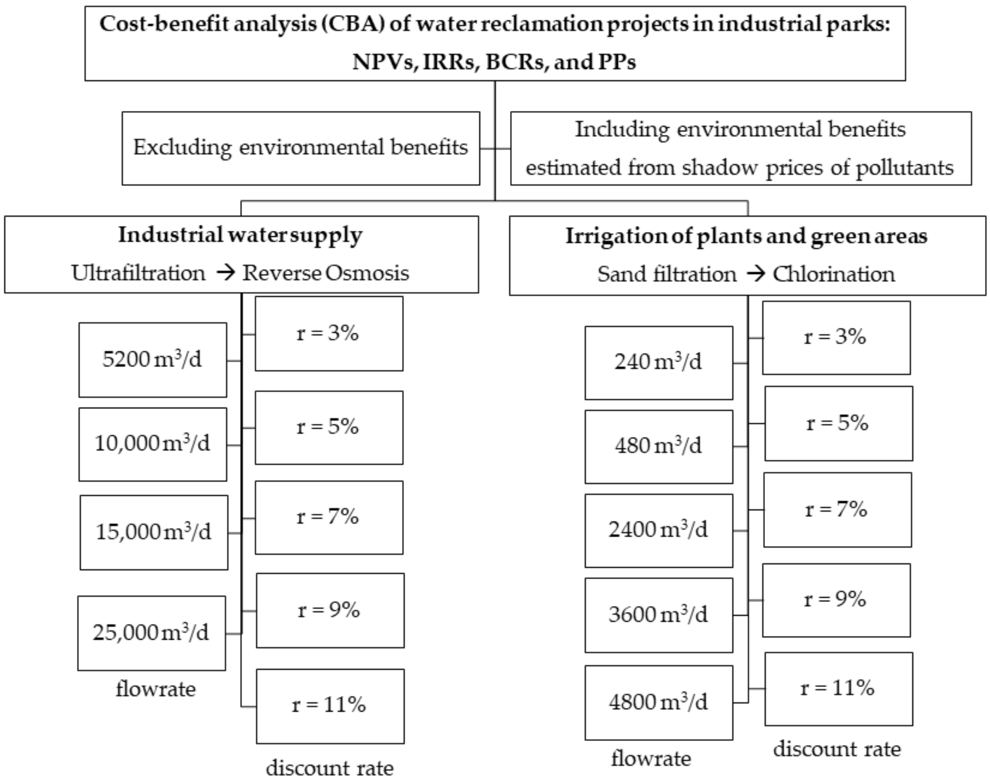

Figure 2. Methodology flowchart of the CBA of water reclamation projects in industrial parks.

NPV is the difference between a project's benefits and its cost over the project's lifetime, as shown in Equation (3). A 20-year lifespan was assumed for all water reclamation plants [13]. Discount rates of 3%, 5%, 7%, 9%, and 11% were used in the analysis, covering the rates commonly used for water projects in Thailand and internationally [13,41,42]. In 2020, the Comptroller General's Department, Thailand, recommended the use of a 5% lending interest rate to estimate the reference prices of construction projects. The social discount rate recommended by the Asian Development Bank (ADB) is 9% [43]. For the private sector, discount rates can be considered through weighted average cost of capital analysis to reflect the opportunity cost of private investment, which largely depends on the capital structure of companies and can be as high as 11%. Alternatively, lending interest rates can be adopted as discount rates. In Thailand, for loans from four major commercial banks, the minimum retail rate is 6.75% [44]. However, if projects are eligible to receive loans from the Environment Fund in Thailand, the interest rates are as low as 2–3% [45]. Nevertheless, large private companies can often afford to undertake projects with environmental benefits as their corporate social responsibility projects, regardless of whether they yield no or low profits. Water reclamation projects may fall into this category, where the discount rates used are usually low. Therefore, the discount rates of 3% to 11% were chosen in this study to cover typical ranges of discount rates.

$$\mathrm{NPV} = \sum_{t=0}^{n} \frac{-C_t + B_t}{(1+r)^t} \tag{3}$$

where

C_t = costs in year t
B_t = benefits in year t
r = discount rate
n = project's lifetime (20 years)

Costs (C_t) and benefits (B_t) of different scenarios are summarized in Table S4. If the result of the calculation is an NPV that is ≥ 0, then a project is economically acceptable;

however, if the result of the calculation is an NPV that is <0, then a project is not acceptable from an economic perspective.

The IRR is used to estimate the profitability of potential investments. The IRR is a discount rate that makes the NPV of all cash flows equal to zero, as shown in Equation (4). A project is economically feasible if the IRR is $\geq$ r.

$$\sum_{t=0}^{n} \frac{-C_t + B_t}{(1 + IRR)^t} = 0 \tag{4}$$

where

C_t = costs in year t
B_t = benefits in year t
n = project's lifetime (20 years)

In CBA, the BCR is another useful indicator. It is defined as the ratio of project benefits to project costs, as shown in Equation (5). Project implementation is acceptable if the BCR is $\geq$1.

$$\text{BCR ratio} = \frac{\sum_{t=0}^{n-1} \frac{B_t}{(1+r)^t}}{\sum_{t=0}^{n-1} \frac{C_t}{(1+r)^t}} \tag{5}$$

where

C_t = costs in year t
B_t = benefits in year t
r = discount rate
n = project's lifetime (20 years)

The PP is the time at which the benefits of a project surpass its costs, as shown in Equation (6). In other words, in the year after the PP of a project, the net gains or benefits of the project become visible.

$$PP = \text{number of years before payback} + \frac{\text{unrecovered present value}}{\text{present value of cash flows in payback year}} \tag{6}$$

3. Results and Discussion

3.1. Cost–Benefit Analysis of Water Reclamation Projects for Industrial Water Supply

CBAs of water reclamation projects for industrial water supply were conducted based on wastewater flow rates of 5200, 10,000, 15,000, and 25,000 m^3/day. The NPVs of water reclamation projects for industrial water supply for cases that included and excluded environmental benefits are shown in Figure 3 (Table S5). The details of the costs and benefits in the NPVs are summarized in Table S6. Considering only the direct costs and benefits resulted in NPVs less than zero in all cases, this indicates that the projects were not economically feasible. The total direct benefits of a project were less than the investment and operation and maintenance costs. However, when the environmental benefits of not discharging WWTP effluents into public waters were considered along with the direct costs and benefits, the NPVs were greater than 0 in all cases except for those with a flow rate of 5200 m^3/day and discount rates of 5%, 7%, 9% and 11% and those with flow rates of 10,000 and 25,000 m^3/day and an 11% discount rate.

In all cases, the IRRs were smaller than the fixed discount rates when only the direct costs and benefits were considered, as shown in Table 3. Given that the NPVs of the projects were negative in these cases, it was impossible to calculate the IRRs such that the NPVs became zero. By contrast, when the indirect benefits to the environment were considered together with the direct costs and benefits, in most cases, the IRRs were larger than the chosen discount rates, which ranged from 4.6% to 11.5%.

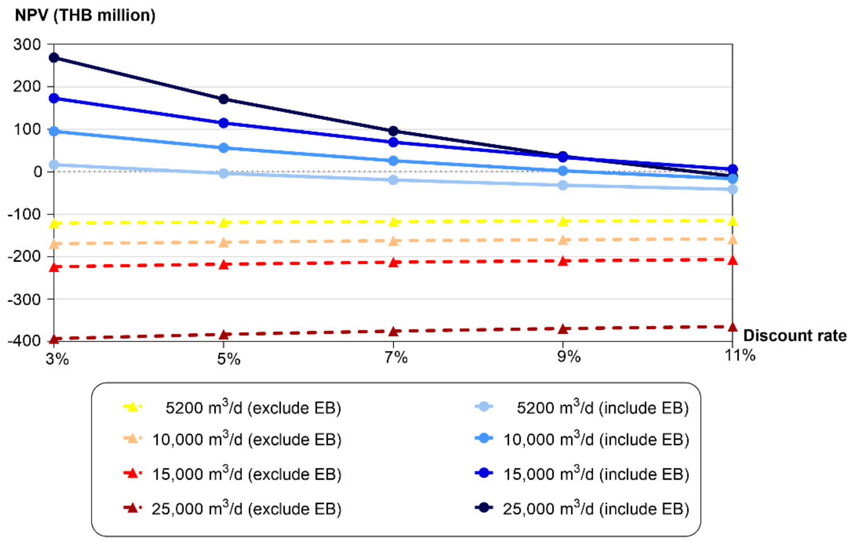

Figure 3. Net present values (NPVs) for water reclamation projects for industrial water supply, with the inclusion or exclusion of environmental benefits (EB).

Table 3. Internal rates of return for water reclamation projects for industrial water supply when including environmental benefits.

Flow Rate (m^3/d)	Including Environmental Benefits
5200	4.6%
10,000	9.2%
15,000	11.5%
25,000	10.5%

Similarly, the BCR results in Figure 4 (Table S5) show that when only the direct benefits were considered, the BCRs were smaller than 1 and ranged from 0.72 to 0.88. However, when the indirect environmental benefits were also considered, the BCRs were 0.90–1.10. These results are consistent with the PPs shown in Figure 5 (Table S5). The PPs were more than 20 years when only direct costs and benefits were considered. When indirect environmental benefits were included, the PPs ranged from 8.9 to more than 20 years. However, if the PP exceeds 20 years, the projects are not considered feasible.

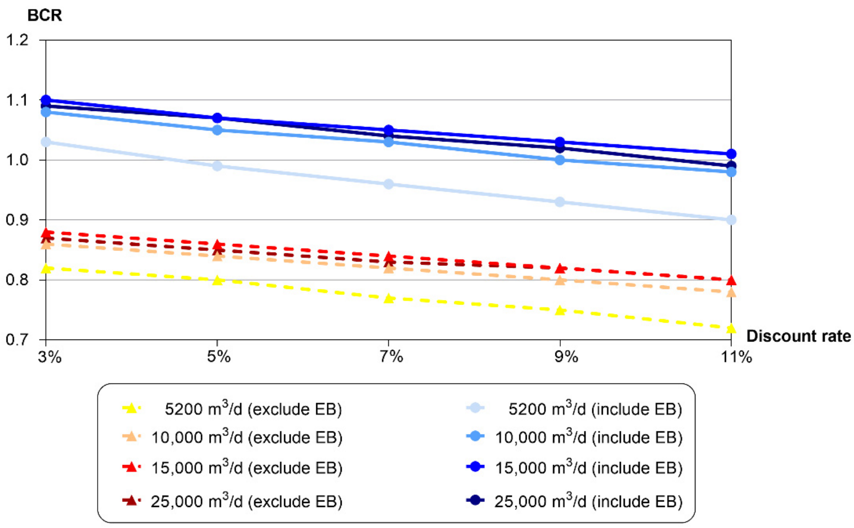

Figure 4. Benefit–cost ratios (BCRs) for water reclamation projects for industrial water supply when including and excluding environmental benefits (EB).

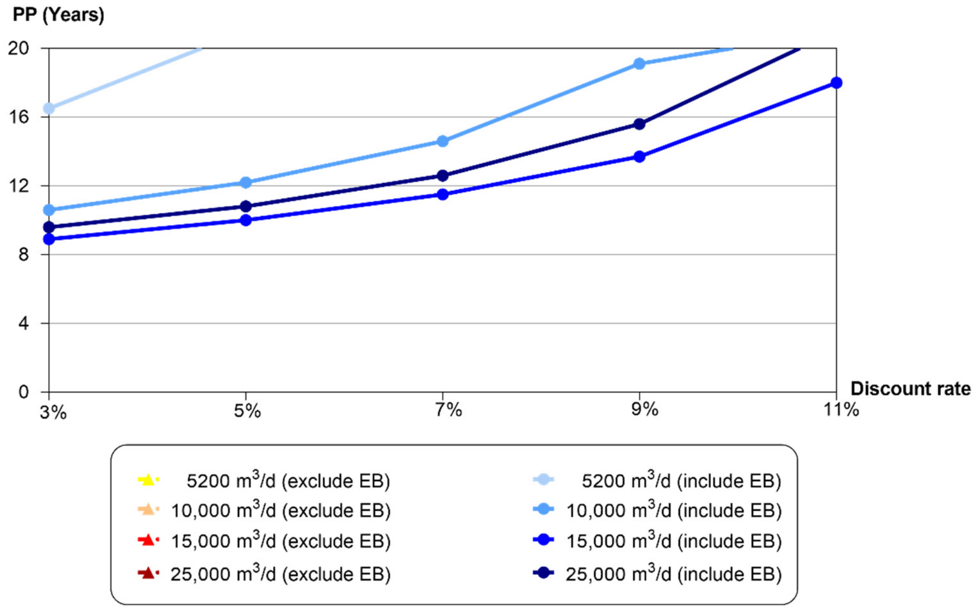

Figure 5. Payback periods (PPs) for water reclamation projects for industrial water supply when including and excluding environmental benefits (EB).

Moreover, the selling prices of reclaimed water appeared to have a major impact on project feasibility. If the selling prices of reclaimed water were too low, the projects were not feasible. Therefore, we further determined the minimum selling prices of reclaimed water that would still make the projects feasible. The results are shown in Table 4. In all cases, when only the direct costs and benefits were considered, the minimum selling prices of reclaimed water ranged from 29.73 to 36.24 THB/m^3. By contrast, when environmental benefits were included, the minimum selling prices were 23.23–29.73 THB/m^3, which were lower than the prices without environmental benefits. At these prices, the NPVs became positive, the BCRs were equal to 1, and the IRRs were equal to the selected discount rates. However, these prices were associated with a PP of 20 years. Therefore, selling prices should be set higher to make the investment more profitable and to reduce the PP.

Table 4. Minimum selling price of reclaimed water (THB) for water reclamation projects for industrial water supply when including and excluding environmental benefits (EB).

Discount Rate	5200 m^3/d		10,000 m^3/d		15,000 m^3/d		25,000 m^3/d	
	Exclude EB	Include EB	Exclude EB	Include EB	Exclude EB	Include EB	Exclude EB	Include EB
3%	31.78	25.28	30.23	23.73	29.73	23.23	29.93	23.43
5%	32.77	26.27	30.93	24.42	30.33	23.83	30.56	24.06
7%	33.85	27.35	31.67	25.17	30.97	24.47	31.25	24.75
9%	35.00	28.50	32.49	25.97	31.66	25.16	31.99	25.49
11%	36.24	29.73	33.33	26.82	32.39	25.88	32.76	26.26

These results clearly show that water reclamation projects for industrial water supply within industrial parks are more economically feasible when environmental benefits are included. However, such projects are not economically feasible under all scenarios when only the direct costs and benefits are considered. This consideration aligns with the perspective of industrial parks, where externalities are generally not considered. In other words, water reclamation for industrial water supply is infeasible from the perspective of industrial parks, and thus, it does not provide financial incentives for project implementation. However, from the public's perspective, the benefits outweigh the costs when all aspects, including environmental benefits, are considered. Therefore, the government may have to intervene to support such projects. Recommendations for governmental support are discussed in Section 3.4.

Similarly, the cost-effectiveness analysis conducted by Giurco et al. (2011) [27] found that financial support in the form of a capital grant and a 0% interest loan was required for industrial water reuse projects to be financially feasible. Water reuse options were found to be more expensive than other water supply options available in the region under study (Port Melbourne, Australia). Therefore, financial assistance should be offered to businesses as an incentive to implement water reuse projects [26].

The CBA of water reclamation projects using effluents from municipal WWTPs in Beijing, China, was conducted by Fan et al. (2015) [16]. In their study, reclaimed water (680 million m^3 in 2010) was used for industrial reuse (20%), agricultural irrigation (47%), environmental reuse (30%), and miscellaneous urban reuse (3%). Both internal costs and benefits as well as positive and negative externalities, including environmental benefits, public health impacts, and groundwater recharge and pollution, were considered in the CBA [16]. The CBA revealed a relatively high BCR of 1.7 when externalities were included, providing further incentives for project implementation.

The environmental benefits of water reuse in a model industrial park were previously analyzed using LCA for several environmental categories, including climate change, freshwater eutrophication, marine eutrophication, and resource depletion (minerals, fossils, renewables, as well as water) [27]. All water reuse options in the industrial park, which was assumed to be located in Germany, provided environmental benefits for all environmental categories, except resource depletion. Similarly, using LCA, Tong et al. (2013) [19] evaluated the environmental impacts of water reuse in an industrial park in China. Their results revealed the environmental benefits of water reuse. The LCA conducted in previous studies clearly demonstrated the environmental benefits of water reuse in industrial parks. The results of our study reemphasize the importance of the environmental benefits associated with water reclamation projects, which, when factored into the CBA, can strongly influence economic feasibility.

3.2. Cost–Benefit Analysis of Water Reclamation Projects for the Irrigation of Plants and Green Areas

Water reclamation for the irrigation of plants and green areas provides several direct and indirect benefits, including revenues from the sale of reclaimed water, savings on fertilizer costs due to the nitrogen and phosphorus contents in reclaimed water, and environmental benefits from not discharging WWTP effluent into public waters. Feasibility studies of water reclamation projects for the irrigation of plants and green areas in industrial parks with post-treatment processes consisting of sand filtration and chlorine disinfection were conducted under wastewater flow rates of 240, 480, 2400, 3600, and 4800 m^3/day. The NPVs were greater than 0 in all cases, regardless of whether the indirect benefits to the environment were included or not (Figure 6, Table S7). The details of the costs and benefits in the NPVs are summarized in Table S8. Notably, the investment and operation and maintenance costs were much lower than those for water reclamation projects for industrial water supply, as membrane units were not included in the treatment system. The selling prices of reclaimed water (12 THB/m^3) appeared to be high. As a result, the benefits exceed the investment and operation and maintenance costs. Nevertheless, when the indirect benefits to the environment were included, the NPVs were greater than the analyses that considered only the direct costs and benefits.

In all cases, the IRRs were higher than the fixed discount rates (Table 5). When only the direct costs and benefits were considered, the IRRs ranged from 45.5% to 69.2%. When indirect environmental benefits were included, the IRRs ranged from 68.0% to 103.3%. Further, the BCRs were greater than 1 in all cases, as shown in Figure 7 (Table S7), ranging from 2.44 to 3.78 when only the direct costs and benefits were considered, and from 3.42 to 5.30 when environmental benefits were included.

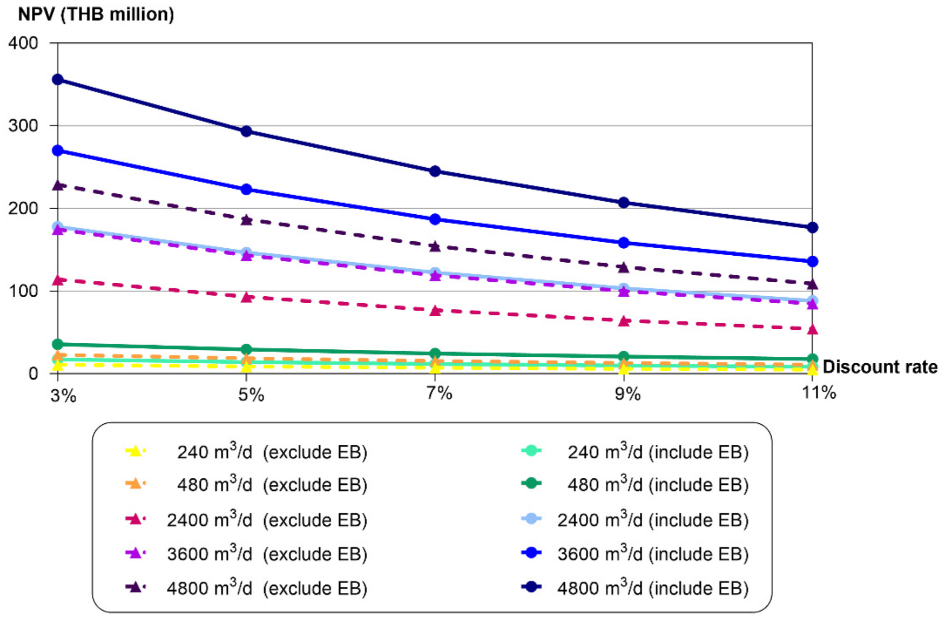

Figure 6. NPVs for water reclamation projects for the irrigation of plants and green areas when including and excluding environmental benefits (EB).

Table 5. Internal rates of return for water reclamation projects for the irrigation of plants and green areas when including and excluding environmental benefits (EB).

Flow Rate (m^3/d)	Exclude EB	Include EB
240	45.5%	68.0%
480	60.5%	90.2%
2400	58.6%	87.5%
3600	69.2%	103.3%
4800	59.4%	88.6%

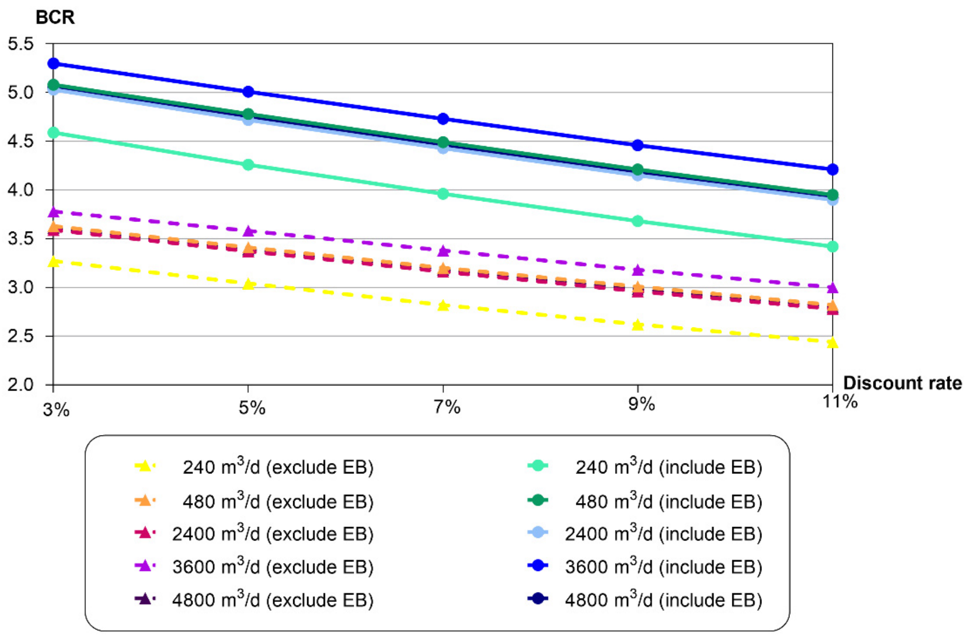

Figure 7. Benefit–cost ratios (BCRs) for water reclamation projects for the irrigation of plants and green areas when including and excluding environmental benefits (EB).

As shown in Figure 8 (Table S7), the PPs ranged from 1.5 to 2.7 years when only the direct costs and benefits were considered, and they were between 1.0 and 1.7 years when the indirect environmental benefits were considered together with the direct benefits. In summary, the PP was always less than 3 years, indicating a good investment.

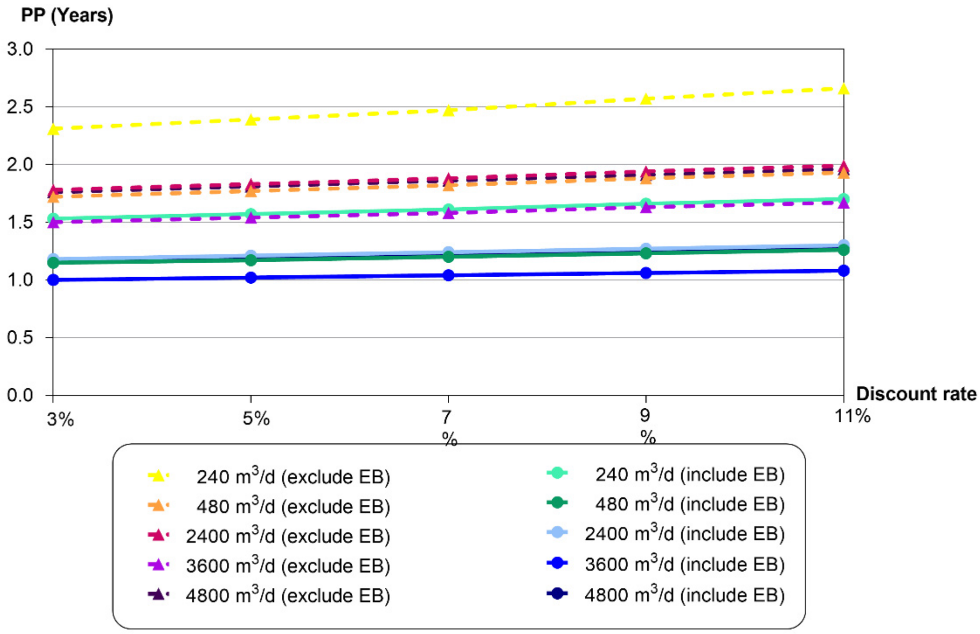

Figure 8. Payback periods (PPs) for water reclamation projects for the irrigation of plants and green areas when including and excluding environmental benefits (EB).

According to the feasibility analyses, all cases were highly cost-effective. Table 6 shows that the minimum selling prices were well below 12 THB/m^3 in all cases. For cases where only the direct costs and benefits were evaluated, the minimum selling price of reclaimed water ranged from 3.06 to 4.83 THB/m^3. At these prices, the NPVs became positive, the BCRs were equal to 1, and the IRRs were equal to the selected discount rates. Moreover, the minimum selling price decreased to zero when environmental benefits were included. In other words, reclaimed water used for the irrigation of plants and green areas can be offered free of charge. The NPVs were positive at these prices, and the BCRs were 1.01–1.57. The IRRs were 11.3–18.8%, well above the discount rates used, while the PPs were 5.7–18.9 years.

Table 6. Minimum selling price of reclaimed water (THB) for water reclamation projects for the irrigation of plants and green areas when including and excluding environmental benefits (EB).

Discount Rate	240 m^3/d		480 m^3/d		2400 m^3/d		3600 m^3/d		4800 m^3/d	
	Exclude EB	Include EB	Exclude EB	Include EB	Exclude EB	Include EB	Exclude EB	Include EB	Exclude EB	Include EB
3%	3.56	0.00	3.20	0.00	3.24	0.00	3.06	0.00	3.22	0.00
5%	3.85	0.00	3.42	0.00	3.46	0.00	3.25	0.00	3.44	0.00
7%	4.15	0.00	3.65	0.00	3.70	0.00	3.67	0.00	3.67	0.00
9%	4.48	0.00	3.90	0.00	3.95	0.00	3.67	0.00	3.93	0.00
11%	4.83	0.00	4.16	0.00	4.22	0.00	3.90	0.00	4.19	0.00

From the CBA of water reclamation projects for the irrigation of plants and green areas within industrial parks, projects are profitable for all scenarios, regardless of whether environmental benefits are included. Therefore, from the perspective of industrial parks, there are financial incentives for project implementation. Nevertheless, when including environmental benefits, projects had higher NPVs, IRRs, and BCRs and lower PPs compared with cases excluding environmental benefits.

The findings of this study are consistent with those of the CBAs of projects for the reclamation of effluents from municipal WWTPs for irrigation, recreation, and environmental purposes, which found that projects were more economically feasible when externalities such as environmental and social benefits were included [13,15,17]. Verlicchi et al. (2012) [15] evaluated the feasibility of using reclaimed wastewater from a central WWTP in Po Valley, Italy, for irrigation and environmental purposes. The reclamation treatment train consisted of rapid sand filtration, a horizontal subsurface flow bed, and a lagoon. The results suggested that the agricultural, environmental, financial, and recreational benefits offset the high construction costs, thereby making the project economically feasible [15]. Similarly, Arena et al. (2020) [17] conducted a CBA on a reclamation project in Puglia, Italy, which reused effluent from a municipal WWTP for irrigation, and the CBA considered environmental and recreational benefits. The water reclamation units included clariflocculation, filtration, and ultraviolet (UV) disinfection. In almost all cases, environmental benefits must be included to make a project economically feasible.

Molinos-Senante et al. (2011) [13] conducted CBA on 13 WWTP in the Valencia region of Spain that reused effluent for environmental purposes. Their results suggested that some projects (4 out of 13) were not economically feasible when only the internal costs and benefits were assessed, whereas all projects were feasible when externalities, that is, environmental benefits, were included. However, the water reclamation system in the Molinos-Senante et al. study [13] was unclear and might include secondary treatment and/or membrane units, differing from this study and the studies conducted by Verlicchi et al. (2012) [15] and Arena et al. (2020) [17]. Despite the differences in water reclamation facilities, the inclusion of the environmental benefits similarly improved the economic feasibility of projects.

Similarly, LCA and eco-efficiency assessment have pointed to a similar direction that water reclamation for irrigation delivered economic and environmental benefits [10,46], although the results are likely site-specific [47]. An LCA study by Meneses et al. (2010) [10] demonstrated that the agricultural use of reclaimed water from a WWTP located on the Mediterranean coast offers environmental and economic benefits, especially when compared to desalinated water, and that water reclamation should be encouraged when freshwater is scarce. Based on an eco-efficiency assessment, Canaj et al. (2021) [46] suggested that reclaimed water could be used to generate an economically profitable yield of vineyard cultivation in Acquaviva Delle Fonti, Italy while also offering net environmental benefits.

3.3. Practical Implications

Comparing the two options, we observed that water reclamation projects for the irrigation of plants and green areas are considerably more cost-effective than those for industrial water supply. Therefore, the irrigation of plants and green areas is considered a recommended entry point for water reclamation in industrial parks due to its high NPVs, IRRs, and BCRs and short PPs (<3 years). However, the water demand for irrigation in industrial parks is generally low, not more than 23% of the WWTP effluent, based on the actual amount of irrigation water in industrial parks in Chonburi (Table S9). Therefore, another water reclamation option, such as reclaimed water for industrial water supply, can be combined to achieve a higher percentages of water reuse.

In this study, a wide range of discount rates was applied in the feasibility studies to provide an overall picture of how environmental benefits affect the feasibility of water reclamation projects. It was not our intent to perform feasibility studies for specific projects. Investments in water reclamation projects could be made by different companies with different discount rates. Given that each company may have vastly different financial costs, lending interest rates, and/or shareholder returns, discount rates are likely to vary widely. It is recommended that the results of this study be used with regard to appropriately selected discount rates.

3.4. Recommendations for Governmental Support

The economic feasibility analyses conducted in this study indicate that water reclamation projects for industrial water supply are infeasible without accounting for environmental benefits. Given that pollution discharge fees do not exist in Thailand or in many developing countries, environmental benefits currently do not directly benefit the industrial sector. Their incentives for pursuing water reclamation projects are likely to be limited. Environmental benefits often benefit the general public. As a result, the government should establish supportive policies to ensure the success of such water reclamation efforts.

Governmental support for water reclamation projects can be in the form of funding support for investment in water reclamation projects [48,49], the addition of adders to the prices of reclaimed water, or tax reductions for businesses that invest in water reclamation projects [50]. These measures can be chosen in a variety of ways, depending on the government and local context. Economic feasibility analyses, such as those undertaken in this study, may also aid in determining the appropriate level of support. For instance, funding support for water reclamation projects could be assessed using the difference between the NPVs with and without environmental benefits. The amount of the adders added to reclaimed water prices can be estimated by comparing the minimum selling prices of reclaimed water with and without consideration of the environmental benefits. Tax savings should be proportional to the environmental benefits created by such projects. Notably, giving low-interest loans did not appear to make water reclamation projects economically feasible, as the IRRs were negative for all flow rates when environmental benefits were excluded.

Although water reclamation projects for the irrigation of plants and green areas were found to be economically feasible, even without considering environmental benefits, governmental support is still considered beneficial because it can increase the incentives for investing in such projects. Governmental support for water reclamation projects for the irrigation of plants and green areas could take the form of tax reductions or low-interest loans.

The government can also play an important role in initiating technology adoption and in developing a regulatory framework, indicators, and monitoring procedures to ensure transparency and to guarantee health and safety, ultimately leading to public acceptance of water reclamation.

3.5. Limitations and Suggestions for Future Research

The CBA of water reclamation projects in industrial parks conducted in this study shows the importance of environmental benefits of water reclamation projects, which increase the economic feasibility of the projects when they are taken into account. However, it should be noted that the CBA is based on many assumptions, and the applicability of the results critically depends on the validity of the assumptions. For example, the water treatment technology used in a targeted industrial park could be different from the ones chosen in this study, namely, UF and RO for water reclamation for industrial water supply and sand filtration, followed by chlorination for irrigation of plants and green areas, resulting in different costs of construction, operation, and maintenance. Further, the flow rate of irrigation water for each industrial park is quite specific. The amount of water supply for irrigation is uncontrollable and depends on the vegetation area, rainfall, evapotranspiration, season, and other factors related to water use by vegetation. Rough estimates of irrigation water in industrial parks might be obtained based on their green areas using the value suggested for calculating irrigation water demand in public parks, which is 1.7 mm/d in Thailand [51]. Taking into consideration local meteorological conditions and grass evapotranspiration, the irrigation water demands should be calculated as shown in Text S1, Tables S10 and S11. The calculation was made for grass as a representative crop, which resulted in an irrigation water demand of 1.9 mm/d in Chonburi. With this irrigation water demand, the irrigated green areas based on the flow rate scenarios would be in the range of 9–177 ha (Table S12). Although we conducted economic feasibility studies for a wide range of irrigation water flow rates (240–4800 m^3/d), it is possible that the irrigation water flow rate for a specific industrial park would be out of this range, particularly at low flow rates, such as industrial parks I2–I4 (43–56 m^3/d) in Chonburi (Table S9). In these cases, the results of this study would not be applicable. Furthermore, it was assumed in the CBA that irrigation water would not be large enough to infiltrate groundwater and that there would be no adverse environmental impacts on soil and groundwater. Indeed, these assumptions can be considered limitations of our study, as they may not be true; thus, the environmental impacts of irrigation by reclaimed water should be considered in future studies.

Further, the environmental benefits of not releasing heavy metals into water bodies when wastewater treatment plant effluent is reclaimed were not considered in this study, as their shadow prices are not currently available. Research on the environmental costs of pollutants other than COD, SS, N, and P, such as heavy metals, chemicals, and emerging pollutants, is still needed. Further research is also required on the ecosystem service values resulting from water reclamation projects in industrial parks. The socioeconomic impacts of water reclamation projects in industrial parks on other stakeholders, such as communities and the public, were also not considered in this study. For example, water reclamation in industrial parks can reduce overall water demand, making more water available to other sectors, such as agriculture, especially during drought periods. Additionally, there are health benefits to not releasing pollutants into the environment, which may result in less human exposure to these pollutants. Future research could translate and incorporate all aspects of environmental impacts analyzed in detail in LCA into CBA. The costs and benefits associated with these impacts could demonstrate the full value of water reclamation projects, potentially making them more feasible and appealing.

4. Conclusions

Water reclamation projects for the irrigation of plants and green areas with post-treatment consisting of sand filtration and chlorination in industrial parks were feasible regardless of the environmental benefits. Moreover, reclaimed water for irrigation could be given for free if environmental benefits are considered. However, in many cases, water reclamation projects for industrial water supply consisting of UF and RO, which were otherwise financially infeasible, became feasible when environmental benefits were considered. Comparing the two options, we observed that water reclamation for irrigation was substantially more cost-effective than the industrial water supply. As water reclamation projects often benefit the general public, the government should provide supportive measures to encourage their implementation and ensure their success. Nevertheless, the CBA in this study has certain limitations, as the environmental costs associated with using reclaimed water for irrigation to soil and groundwater if provided in excess were not considered. The entire benefits of water reclamation projects, including the environmental benefits of not releasing heavy metals, chemicals, or emerging pollutants, and socioeconomic and health benefits to communities and the general public, still require more investigation in the future.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/w14071172/s1, Table S1: Flow rates of wastewater to wastewater treatment plants in industrial parks in Chonburi and Rayong, which are among the most important industrial provinces in the Eastern Economic Corridor (EEC), Thailand. Table S2: Concentrations of pollutants in the wastewater treatment plant effluents of industrial estates in Chonburi, according to our 2018 survey. Table S3: Average concentrations of pollutants and their environmental damage costs. Table S4: Costs and benefits of different scenarios. Table S5: Net present values (NPVs), internal rates of return (IRRs), benefit–cost ratios (BCRs), and payback periods (PPs) for water reclamation projects for industrial water supply when including and excluding environmental benefits. Table S6: Costs and benefits in the net present values (NPVs) of water reclamation projects for industrial water supply. Table S7: Net present values (NPVs), internal rates of return (IRRs), benefit–cost ratios (BCRs), and payback periods (PPs) for water reclamation projects for irrigation of plants and green areas when including and excluding environmental benefits. Table S8: Costs and benefits in the net present values (NPVs) of water reclamation projects for irrigation of plants and green areas. Table S9: Actual amount of irrigation water in industrial parks in Chonburi in 2018. Table S10: Effective monthly rainfall in Chonburi. Table S11: Irrigation water demand of grass in Chonburi. Table S12: The irrigated green areas based on flow rate scenarios. Text S1: Calculation of irrigation water demand.

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