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ABSTRACT

One of the most effective strategies to mitigate water shortages worldwide is to reuse the treated wastewater for freshwater production employing reverse osmosis (RO) technology. This strategy is appropriate in urban areas of arid or semi-arid regions as it can provide a sustainable and reliable water source close to the consumers. One of the drawbacks of RO is the high variability of production costs due to the electricity intensity. In addition, depending on the electricity source, it can also result in substantial environmental costs.

This study showed that upgrading pumping and RO membrane systems of a wastewater reuse plant in Cyprus can significantly alleviate these drawbacks in terms cost, water recovery rate, and air pollution. The water recovery rate of the upgraded RO plant increased from 43.2 to 75 percent which results in a substantial net financial benefit due to less quantity of wastewater to be purchased and more potable water to be produced. The upgraded system also reduced the electricity requirement from 3.63 kWh/m3 to 1.92 kWh/m3. Pollution emissions decreased substantially because of the reduction in electricity requirements. The beneficiaries of these lower emissions costs are the residents of Cyprus and global society. Overall, the benefit of upgrading the plant is highly attractive with more than 65 percent of annual real internal rates of re-turn in financial and economic terms. Positive net present values are realized for all the scenarios considered.

Keywords: circular economy; reused wastewater; reverse osmosis; levelized cost; economic cost; membrane technologies; emission cost; environmental externalities; distributive analysis; energy saving

JEL Classification: I38, L95, H43, Q25

1. Introduction

Over the years, many technological improvements in RO membranes have significantly impacted the operating costs of producing clean water [1]. The energy consumption and the levelized cost of producing clean water are significantly impacted by increased energy recovery technology, altered feed spacer designs, and enhanced pump efficiency [2-4]. The development of more advanced membrane materials has led to membranes that are more durable, resistant to fouling, and able to handle higher pressures. This has increased the lifespan of the membranes, reduced maintenance costs, and improved the overall efficiency of the RO process [5].

Furthermore, advanced RO membrane technologies enable RO systems to achieve higher rejection rates for a wider range of contaminants than older membranes. This means that less pre-treatment is required, significantly reducing operating costs [6].

Advances in membrane design have led to membranes requiring less energy. This is due to the development of thinner membranes that require less pressure to push water through, as well as new materials that allow for more efficient transport of water molecules [7].

Another improvement has been the ability to increase the surface area of the membranes, which allows for more water to be processed at once. This increases the efficiency of the process and reduces the number of membranes required, which can significantly lower operating costs [7].

Finally, advancements in monitoring and control systems have allowed for more precise control of the RO process. This enables operators to optimize the process, reducing waste and energy consumption, as well as by improving the system's efficiency [8].

Overall, these technological improvements in RO membranes have significantly reduced the operating costs of producing clean water. By increasing efficiency, reducing maintenance costs, and improving the process' overall performance, these advancements have made it more cost-effective to provide safe and clean water to communities around the world.

Another avenue for reducing the cost of potable water via RO systems is using treated wastewater, instead of brackish water or seawater, as the feedstock for the RO systems. When compared to seawater or brackish water for treatment, the wastewater provided as the input to RO system in question is constantly accessible and usually with lower levels of total dissolved solids (TDS) and total suspended solids (TSS), which thus results in a lower cost of treatment through RO.

A unique feature of this research is that it is based on actual quantitative operating information, with prices and costs that are not subject to the multitude of explicit and implicit subsidies that usually apply when public utility data are employed in such an analysis [9,10]. Hence, the financial and economic impacts of this upgrade in technology reflect the true market values. In addition, we can relate the electricity usage of this plant to a particular type of thermal power generation plant. North Cyprus does not receive significant amounts of electricity through interconnections with other electricity systems. In this way, the precise impact of the additional electricity requirements can be quantified and monetized for the health impacts of changing the RO technology used. Furthermore, because Cyprus is an island, the local environmental impacts are inflicted on the resident communities of North and South Cyprus, with few spillovers to other countries. While the GHG effects are widely dispersed, the local pollution impacts can be quantified, and the impacted stakeholders can be identified.

Unfortunately, RO systems are highly electricity-intensive [9]. Even in the RO of treated wastewater, the cost of electricity can be 75% of the levelized cost of the potable water produced [11]. At the same time, the pollution created by the generation of this electricity is the primary source of the negative environmental externalities arising from the treatment of wastewater and RO [12]. In North Cyprus, where the electricity is produced by thermal generation plants using heavy fuel oil (HFO), the increased health care costs and early deaths of local residents represent a loss of up to 30% of the cost of electricity. When the cost of greenhouse gas (GHG) emissions caused by global warming is added, the total estimated damage caused by emissions from electricity generation amounts to 42% of the financial price that is charged for the electricity [11].

The research hypothesis of this study is that the levelized cost per cubic meter of freshwater that is produced from wastewater via the process of reverse osmosis will be reduced significantly in both financial and economic terms by upgrading the RO plants with current membrane and pumping technologies. Through this analysis, we estimate the significance of the financial savings that are likely to be received by the owners of this facility, as well as the significance of the economic benefits that are received by the households affected by the lower emissions of pollution gases due to his upgrade. The analysis uses an integrated investment appraisal methodology where the financial, economic, environmental, and stakeholder impacts of both the existing RO plant and the upgraded one are evaluated in an integrated and consistent fashion [2-13].

Given that this water supply system is privately owned and not subsidized, each of these dimensions of analysis is critical. Unless the upgrade is financially attractive, it is unlikely to take place. At the same time, from society's point of view, the economic cost of supplying this water, including the health and the GHG costs arising from the pollution that is produced by the additional requirements for electricity generation, is critical from a government policy perspective. Furthermore, mitigating the risks of water shortages at the lowest financial and economic cost is an issue of central importance to the community, who are the principal stakeholders that this water system serves.

2. Case Study

Cyprus experiences a wide range of temperatures; hence, water demands fluctuate according to the season. North Cyprus has experienced a water deficit since 1960 due to insufficient access to freshwater resources, the effects of the climate, and the high evaporation rate [14]. The island relies primarily on groundwater for its supply because there are no perennial rivers. Further, seawater intrusion results from the excessive freshwater withdrawal from aquifers, driven by the gradually increasing water demand, which has thus made the scarcity even more acute [15]. Since 2015, the water scarcity in North Cyprus has primarily been alleviated through the transport of freshwater directly from Turkey to North Cyprus via an undersea pipeline. This water is transported from the Alakopru Dam reservoir in Turkey to the Gecitkoy Dam reservoir in Kyrenia, North Cyprus [16]. The Gecitkoy Dam distributes the water supply to consumers through municipal water distribution systems. However, these distribution systems are only in North Cyprus. They are old and need to be upgraded or replaced. Local water shortages occasionally occur, causing water consumers to maintain alternate sources, such as wells and RO systems, to mitigate the risk of such shortages.

South Cyprus has faced a similar situation of water shortages. The strategy of South Cyprus in the period of 1970 to the 1990s was to build over 100 dams to capture the precipitation as it flows from the mountains and seasonal rivers. This water supply program provided an adequate supply of water for a period, but due to the high variability of rainfall and the growing demand for potable water, periodic shortages have occurred. During 1997-2021, two desalination plants were built to address the shortage of potable water during years of low rainfall. In 2008-9, South Cyprus suffered a severe water crisis where they transported potable water by tanker from Greece. This experience accelerated the installation of desalination plants, with two more plants completed in 2012 and 2013, with a third plant completed in 2018. In total, their capacity can produce approximately 300,000 m^3 of potable water daily. However, during normal rainfall years, these plants operate far below their potential capacity. All of these plants operate along the coast of South Cyprus, with the brine from the RO process being returned to the sea [17].

The community that is the focus of the analysis for this article is located inland from the coast of North Cyprus. The consumers of water in this community are from many sectors; these include a major university, primary and secondary schools, a large dairy farm, vineyards, several manufacturing enterprises, and many households. The size of the student population changes significantly between the months of the academic year and the holiday periods. In addition, the demand for water from the dairy farm is greatly increased during the hot summer months.

These factors are key determinants of the variability of the demand for water over time. The social costs of temporary shortages are also very substantial. No crop irrigation exists in this community, so it cannot divert water from this low-value use when shortages arise. For the community to be sustainable, it needs a cost-effective system for managing the water supply sources, such that significant water shortages do not occur.

Fortunately, the community that is the focus of this research has easy access to a large supply of treated wastewater. The RO system considered here is approximately one kilometer from the Nicosia Wastewater Treatment Plant (NWTP). The NWTP is a bi-communal facility in North Nicosia. It is the largest WWTP on the island of Cyprus and Europe's second-largest wastewater treatment facility.

It is a tertiary treatment plant producing high-quality treated sewerage effluent (TSE). It was designed to produce treated wastewater of a high enough purity to be used directly for agriculture. It also produces treated wastewater of a higher quality than normal EU standards. Due to the low level of total dissolved solids and other containments, it can be made potable through the RO process at a lower cost than if brackish water or seawater was used. The NWTP has been operational since July 2013, supplying daily treated wastewater of over 30,000 m3 [18-19].

To address the risk of water shortages, the community built a reverse osmosis (RO) plant as a flexible source of potable water to mitigate any water shortages that might arise. In North Cyprus, the plant owned by the Levent Group is the only RO system operating on a significant scale, as well as the only one that uses treated wastewater as feedstock. The small-scale RO plants can be a solution for overcoming the water stress and volatility in the supply and demand gaps in arid and semi- arid regions. These small RO systems become particularly practical when employing treated wastewater as the feedwater for the RO plants that are producing potable water [20].

Besides the RO of wastewater, this community's primary water sources are wells and municipal water utilities. On average, the community consumes approximately 3,000 m^3 of water daily. Around 1,700 m^3 of the water consumed per day is provided by the municipal water utilities and 700 m^3 from wells. The remainder is supplied by the RO plant using treated wastewater as its input. The plant operates as needed over the full range of its capacities—ranging from operating for only a few hours daily to operating at full capacity. On average, over a year, the RO plant currently operates at about 75% of its full capacity.

3. Methodology

3.1 Technical Specifications of Existing and Upgraded RO Systems

The pumps on the existing RO device are CNP CDL42-110 model pumps. The high-pressure pump operates at 21 bars or 2.1 Mpa.

Further, 88 m3/hour of treated wastewater enters the system as feedwater, while 38 m^3/hour potable water is produced, and 50 m^3/hour of water is discharged as brackish water into the aquifers with the efficiency of 43.2%. The total amount of electricity required for 43.2% efficiency is 3.63 kW/m^3. The existing system needs four hours of backwash per each operating day to reopen the clogged membrane pores (Table 1, col. 2).

The upgraded system will use a new technology transmission pump to reduce the input water flow rate from 88 m^3/hour to 60 m^3/hour. The new system will produce a 31.88% saving in water inflow requirements. Ten vessels containing six membranes, from a total of 60 membranes, will be used in the new system. The desalination in this system will be carried out in two stages: First, the wastewater will pass through the first six membrane vessels (containing 36 membranes). In stage two, the discharge from stage one will pass through the last four vessels of the membrane (containing 24 membranes). This two-stage process system will lead to a reduction in brine discharge, thus increasing the efficiency of the new plant. In this system, the electricity required to produce potable water is 1.92 kW/m^3. For such a small RO system, the energy consumption rate is a critical factor [21].

In this system, from 60 m^3/hour of input water, 45 m^3/hour of potable water will instead be produced. In this case, the system's efficiency in terms of water use would be 75%. The time required for backwash will be two hours every two months or, on average, 0.03 hours/day (Table 1, row 4).

Due to the new system's reduced water input (60 m^3/hour), a lower chemical dose will be required, thereby resulting in a 32% decrease in chemical requirements.

In the situation that the upgraded plan needs to be shut down because there was no longer a demand for its freshwater production, the 15 minutes of automatic CIP would run without chemicals. An 11 kWh CIP pump must run for 15 minutes throughout this process, and just 1-2 cubic meters of clean water are needed. The standby CIP cost is negligible compared to all the other process costs. Hence, we decided not to include it in our analysis.

Table 1. Efficiency characteristics of the two reverse osmosis technologies.

	New plant	Current plant
Input capacity (actual flow rate due to friction)	60 m^3/hr	88 m^3/hr
Output of potable water per hour operating 20 h/day	45 m^3/hr	38 m^3/hr
Operating RO (maximum)	23.97 hr/day	20 hr/day
Backwash RO	0.03 hr/day	4 hr/day
Efficiency	75%	43.20%
Electricity input per cubic meter	1.92 kWh	3.63 kWh

The input water has the following characteristics: a conductivity of 850 ppm, a water temperature of 25 °C, and a pH of 8.0–8.7, after prefiltration by the UF, SF, and CF. The output water has the following specifications: 40 ppm, 50 uS/cm of conductivity, and a pH of 6.5.

A financial cash flow model for 20 years of operation is built in order to conduct the financial study of the upgraded and existing RO plants. This model is augmented to construct the economic resource flows of both options. The economic analysis incorporates environmental externalities, such as the local and worldwide costs that are imposed by the increased emissions of pollution arising from the electricity generation that is required to operate the existing and the proposed upgraded RO plants.

For comparability, the study is conducted employing three scenarios.

In the first case, we considered the current capacity utilization of the existing plant, which is approximately 75% on average. We determined that the new technology plant would only need to operate at 52% of its capacity to produce the same quantity of water. In this scenario, we aim to determine if the annual volume of the community's water demand remains constant over time and what the net benefit of upgrading the plant would be. In other words, assuming the annual volume of water required does not vary over the next 20 years, and that only the system is upgraded, what would be the net financial, economic, and environmental benefits? As the volumes of water produced by the two plants are the same, it is possible to evaluate whether the cost savings justify upgrading the existing plant.

The second scenario is designed in anticipation that the demand for potable water will rise over time, leading to an increase in the quantity of clean water that is produced by the two facilities. In this instance, we assume the existing plant would run at full capacity, whereas the new technology would produce the same amount of water at 70.47% of its capacity. Since both technologies produce the same amount of water, we can evaluate the financial, economic, and environmental net benefits of the investment of upgrading the plant at this higher annual water production level. With a utilization factor of 70.47%, the new plant could provide approximately the same risk mitigation function as the existing plant now provides. Again, because the volumes of water produced by the two plants are the same, it is possible to evaluate whether the cost savings justify upgrading the existing plant.

In the third case, the comparative analysis estimates the levelized water production cost if the two plants were to be operated at full capacity. A capacity utilization of 100% of the existing plant would operate for 20 hours, with 4 hours of backwash daily. The upgraded plant operating at 100% capacity, will run for 23.97 hours per day with 0.03 hours of average backwash (once every two months for two hours). In this case, because the volumes of water produced are different, it is only possible to calculate and compare the long run levelized cost per cubic meter of water produced by the two systems.

The core research questions are as follows: What are the financial and economic cost savings expected from updating the existing system to one that is more efficient in providing high-quality water, utilizing treated wastewater as an input? What are the financial levelized costs of water for different plant utilization levels? What are the costs and benefits of the economic externalities of the project? Who are the stakeholders whom such an upgrade would impact in terms of upgrading the technology, and by how much?

The objectives of the upgrade are as follows:

- To use the latest technology membrane and to improve the quality of the pumps to boost the system's efficiency from 43.2% to 75%;
- To reduce the electricity requirement of the system;
- To reduce the amount of local and global emissions that are produced by utilizing the energy that is required by the system;
- To replace the current backwash system, which is a manual method, with a clean-in-process system (CIP), which operates relatively quickly and efficiently, thereby reducing the quantity of power and water required for backwash and thus producing less brine discharge;
- To reduce the chemical amount required per one cubic meter produced;
- The overall objective is to reduce the financial, economic, and environmental cost of producing a cubic meter of clean water.

3.2 Estimation of the Costs and Benefits of Upgrading the RO Technology

The data for the analysis of the existing system were obtained from an ex-post analysis of the costs of the current RO plant. These were obtained from the operating records of the Levent Group, Haspolat, North

Cyprus. The operation of this plant receives no subsidies or preferential treatment from the government in any way. The data used for this analysis are reported in Appendix A. The data on the capital and operating costs of the upgraded plant are obtained from a detailed engineering analysis of the upgrade requirements for the installation of the technically most efficient RO membranes and pumps.

These calculations were conducted by a private engineering firm that designs and supplies RO systems, i.e., Polatlar Engineering and Water Treatment Technologies, Nicosia, North Cyprus.

This analysis was carried out for the specific quality of the treated wastewater available for input, and the quality requirements of the potable water that is produced by the system.

The levelized cost of supplying water from the plants was determined by the financial costs of the supply from the RO system at different capacity utilization levels for the two plants. The present value (PV) of the water generated throughout this period for the two technologies was evaluated by discounting each year's quantities of produced water by an 8% discount rate in order to determine the financial and economic levelized cost of the water output over 20 years.

Each component of the subsequent financial, economic, and stakeholder analysis was specified and quantified using the following 21 equations for both plants, where *i*=1 refers to the upgraded plant, and i=2 denotes the existing plant:

The PV of 8% of the water produced over the plant's lifetime was estimated by:

$$PV_i^{PW} = \sum_{t=0}^{t=21} QPW_{it} * (1+r)^{-t} \tag{1}$$

Financial costs were incurred in year *t*:

$$C_{it}{}^{F} = PMX_{it}^{F} + ECX_{it}^{F} + ChCX_{it}^{F} + FO\&MX_{it}^{F} + ICAPEX_{it}^{F} + RCAPEX_{it}^{F} \tag{2}$$

The PV of the financial cost for each plant was estimated according to Equation 3.

$$PVC_{it}^{F} = \sum_{t=0}^{T=21} C_{it}{}^{F} * (1+r)^{-t} \tag{3}$$

The levelized financial cost per cubic meter of pure water expressed in the price level of 2022 (Equation 3/Equation 1):

$$LC^{F}{}_{i} = \frac{\sum_{t=0}^{T=21} C_{it}{}^{F} * (1+r)^{-t}}{\sum_{t=0}^{T=21} QPW_{it} * (1+r)^{-t}} \tag{4}$$

The economic cost in year *t* of each of the plants was estimated using equations 5–8:

$$C_{it}{}^{E} = PM_{it}^{E} + EC_{it}^{E} + ChC_{it}^{E} + FO\&M_{it}^{E} + ICAPE_{it}^{E} + RCAPE_{it}^{E} \tag{5}$$

$$C_{it}{}^{ENC} = PM_{it}^{E} + EC_{it}^{E} + ChC_{it}^{E} + FO\&M_{it}^{E} + ICAPE_{it}^{E} + RCAPE_{it}^{E} + EC_{it}^{NC} \tag{6}$$

$$C_{it}{}^{ECY} = PM_{it}^{E} + EC_{it}^{E} + ChC_{it}^{E} + FO\&M_{it}^{E} + ICAPE_{it}^{E} + RCAPE_{it}^{E} + EC_{it}^{CY} \tag{7}$$

$$C_{it}{}^{EG} = PM_{it}^{E} + EC._{it}^{E} + ChC_{it}^{E} + FO\&M_{it}^{E} + ICAPE_{it}^{E} + RCAPE_{it}^{E} + EC_{it}^{CY} + EC_{it}^{GHG} \tag{8}$$

The PVs of the economic costs for each plant were estimated from each stakeholder's perspective, using equations 9–12.

$$PVC_{it}^{E} = \sum_{t=0}^{T=21} C_{it}{}^{E} * (1+r)^{-t} \tag{9}$$

$$PVC_{it}^{ENC} = \sum_{t=0}^{T=21} C_{it}{}^{ENC} * (1+r)^{-t} \tag{10}$$

$$PVC_{it}^{ENY} = \sum_{t=0}^{T=21} C_{it}{}^{ENY} * (1+r)^{-t} \quad (11)$$

$$PVC_{it}^{EG} = \sum_{t=0}^{T=21} C_{it}{}^{EG} * (1+r)^{-t} \quad (12)$$

The levelized economic costs per cubic meter of the pure water, expressed in 2022 prices for each of the plants, were estimated according to equations 13–16:

$$LC^{E}{}_{i} = \frac{\sum_{t=0}^{T=21} C_{it}{}^{E} * (1+r)^{-t}}{\sum_{t=0}^{T=21} QPW_{it} * (1+r)^{-t}} \quad (13)$$

$$LC^{ENC}{}_{i} = \frac{\sum_{t=0}^{T=21} C_{it}{}^{ENC} * (1+r)^{-t}}{\sum_{t=0}^{T=21} QPW_{it} * (1+r)^{-t}} \quad (14)$$

$$LC^{ECY}{}_{i} = \frac{\sum_{t=0}^{T=21} C_{it}{}^{ECY} * (1+r)^{-t}}{\sum_{t=0}^{T=21} QPW_{it} * (1+r)^{-t}} \quad (15)$$

$$LC^{EG}{}_{i} = \frac{\sum_{t=0}^{T=21} C_{it}{}^{EG} * (1+r)^{-t}}{\sum_{t=0}^{T=21} QPW_{it} * (1+r)^{-t}} \quad (16)$$

The net present values (NPVs) of the investment required to upgrade the RO plant were estimated from the financial and economic perspective of each of the stakeholders, using equations 17–21.

$$NPVC_{t}^{F} = PVC_{2t}^{F} - PVC_{1t}^{F} \quad (17)$$

$$NPVC_{t}^{E} = PVC_{2t}^{E} - PVC_{1t}^{E} \quad (18)$$

$$NPVC_{t}^{ENC} = PVC_{2t}^{ENC} - PVC_{1t}^{ENC} \quad (19)$$

$$NPVC_{t}^{ENY} = PVC_{2t}^{ENY} - PVC_{1t}^{ENY} \quad (20)$$

$$NPVC_{t}^{EG} = PVC_{2t}^{EG} - PVC_{1t}^{EG} \quad (21)$$

Table 2 lists all parameters used in equations 1–21 with their definitions.

Table 2. Table of parameters.

Parameter	Definition
PV_{i}^{PW}	Present value, as of year 0 (2022), of the quantity of water produced by plant *i* over 20 years
r	Financial real discount rate
C_{it}^{F}	Financial cost of plant *i* in year *t*
PMX_{it}^{F}	Financial value of the payment to the municipality for raw water from operations of plant *i*
ECX_{it}^{F}	Total financial electricity cost of pumping from operations of plant *i*
$EChX_{it}^{F}$	Total financial chemical cost from operations of plant *i*
$FO\&MX_{it}^{F}$	Total financial fixed O&M expenditures from the operations of plant *i*
$ICAPEX_{it}^{F}$	Total financial initial capital costs of plant *i*
$RCAPEX_{it}^{F}$	Total financial recurrent capital costs from operations of plant *i*

Parameter	Definition
LC_i^F	Total financial levelized cost of water of plant *i*
C_{it}^E	Economic cost in year *t* (without pollution) of plant *i*
C_{it}^{ENC}	North Cyprus' economic cost in year *t* from operations of plant *i*
C_{it}^{ECY}	Cyprus' economic cost in year *t* from operations of plant *i*
C_{it}^{EG}	Global economic cost in year *t* from operations of plant *i*
PM_{it}^E	Economic value of the payment to the municipality for raw water for operations of plant *i*
EC_{it}^E	Total economic electricity cost of pumping from operations of plant *i*
ChC_{it}^E	Total economic chemical cost from operations of plant *i*
$FO\&M_{it}^E$	Total economic fixed O&M expenditures from operations of plant *i*
$ICAPE_{it}^E$	Total economic initial capital costs of plant *i*
$RCAPE_{it}^E$	Total economic recurrent capital costs from operations of plant *i*
EC_{it}^{NC}	Economic cost of local emissions in North Cyprus from operations of plant *i*
EC_{it}^{CY}	Economic cost of local emissions in all of Cyprus from operations of plant *i*
EC_{it}^{GHG}	Economic cost of GHGs from operations of plant *i*
LC_{22}^E	Economic levelized cost of water (without pollution), in terms of 2022 prices, of plant *i*
LC_i^{ENC}	Total economic levelized cost of water (North Cyprus) of plant *i*
LC_i^{ECY}	Total economic levelized cost of water (all Cyprus) of plant *i*
LC_i^{EG}	Total economic levelized cost of water (global) of plant *i*
PVC_{it}^E	Present value of economic cost in year *t* (without pollution) from operations of plant *i*
PVC_{it}^{ENC}	Present value of North Cyprus economic cost in year *t* from operations of plant *i*
PVC_{it}^{ECY}	Present value of Cyprus economic cost in year *t* from operations of plant *i*
PVC_{it}^{EG}	Present value of global economic cost in year *t* from operations of plant *i*
$NPVC_{it}^F$	Net present value of financial cost in year *t* from operations of plant *i*
$NPVC_{it}^E$	Net present value of economic cost in year *t* (without pollution) from operations of plant *i*
$NPVC_{it}^{ENC}$	Net present value of North Cyprus' economic cost in year *t* from operations of plant *i*
$NPVC_{it}^{ECY}$	Net present value of Cyprus' economic cost in year *t* from operations of plant *i*
$NPVC_{it}^{EG}$	Net present value of global economic cost in year *t* from operations of plant *i*

4. Results and Discussion

4.1. Financial Analysis

4.1.1. Case I: Both Plants Produce the Same Amount of Water as Currently Produced by the Existing Plant (75% Utilization Rate)

Two distinct and comprehensive integrated project models have been developed to assess the quantity of the water produced and all the associated costs over 20 years. The values of the parameters used in the financial-economic models are presented in Appendix A. The treated wastewater is purchased from the Lefkosa Municipality Water Authority at 2.0 T.L. per m³, or approximately 0.10 USD/m³.

The amount of water each plant produces is estimated annually and discounted to the first year of operations through using Equation 1. In this scenario, both plants produce the same amount of water over their lifetimes. The Levent factory operates at an average capacity utilization of 75% for 15 hours per day, while the new facility operates at 52.85% (12.67 hours per day on average) in order to maintain equal production in the two plants. They both produce in PV terms approximately 2,042,670 m³ within the lifetime of 20 years of the project (Table 3, row 1).

The financial costs of each plant are estimated using Equation 2, and the PV of each cost series is discounted back to the year 2022. The cost components are presented in the first column for the upgraded plant and the second column for the existing plant.

The first three variables in Equation 2 are the variable costs of the facility. These include the payment to the municipality for the treated wastewater (PMX_{it}^{F}) and the power cost (ECX_{it}^{F}), which comes mainly from the electricity usage cost of the pumps, as well as the cost of the chemicals ($ChCX_{it}^{F}$). The final three items in Equation (2) refer to the fixed costs of the RO plant. These components include fixed operating and maintenance expenses ($FO\&M_{it}^{E}$), the initial capital cost ($ICAPE_{it}^{E}$), and the recurrent capital cost ($RCAPE_{it}^{E}$). The fixed operating and maintenance costs include the annual cost of spare parts, administrative and accounting expenses, the operator's wages, insurance, external support, and water quality monitoring cost. According to our estimations, the account payable in accounting cost would be 8% of the electricity cost, and the spare cost would be 1% of the CAPEX.

The total variable costs of the new technology plant are 48.5% of the total variable costs of the existing plant while producing the same amount of water (Table 3, row 5). The electricity costs have been reduced to almost half that of the existing plant (from USD 1,281,370 to USD 678,240) (Table 3, row 3). As electricity is the largest cost component of the desalination plants, this reduction in electricity consumption and cost will significantly affect the overall levelized cost of producing one cubic meter of clean water.

The second item showing a significant difference would be the payment to the municipality for the purchase of treated wastewater. Since the new technology would be more efficient than the existing one, it will require less input water and produce less brine than the previous plant to produce the same amount of water. This cost would decrease from USD 473,040 to USD 272,360, producing a savings of USD 200,680 (Table 3, row 2). Technological improvements go a long way in terms of conserving energy and water use, as well as in reducing pollution emissions [22].

Since many of the initial capital costs of the existing plant are sunk costs and will not be utilized in the upgraded facility, they are not included in the capital costs of retaining the existing plant in operation. The PV of the capital cost of continuing with the existing plant is USD 116,760,000 less than those of the new plant, according to Table 3, row 7. The new plant's membranes are more technologically advanced and have a reduced recurring cost for replacement over time. Over the project life cycle, when the cost of replacing the membranes is included, the PV of the incremental capital cost of upgrading the system is reduced to USD 85,250 (Table 3, col. 3, row 9).

Table 3. Present value of the financial output and costs in terms of equal production in the two plants, in 2022 prices.

Row no.		New plant	Current plant	Change in cost
	Capacity utilization (%)	52.85	75	
1	Quantity of water produced ('000) m³	2,042.67	2,042.67	
2	Total payment for wastewater ('000) USD	272.36	473.04	200.68
3	Total electricity cost ('000) USD	678.24	1,281.37	603.13
4	Total chemical cost ('000) USD	6.23	11.92	5.69
5	Total variable cost ('000) USD	856.83	1,766.32	909.49
6	Total fixed O&M costs ('000) USD	205.16	199.18	−5.98
7	Total initial capital costs ('000) USD	294.69	177.93*	−116.76
8	Total recurrent capital costs ('000) USD	202.15	239.63	37.48
9	Total Fixed Cost ('000) USD	701.99	616.74	−85.25
10	Total lifetime financial costs ('000) USD	1,658.82	2,383.07	724.25

* The initial capital cost of the old plant includes storage tanks, carbon filters, sand filters, pipelines, fittings, electricity installations, as well as land and building costs.

It is evident from the results in Table 3 that this is a desirable private investment, with an NPV of 8% of USD 724,240. (Table 3, row 10, col. 3). This saving is 30.4% of the financial cost of the existing plant**.** Its internal rate of return, which is 66%, is another indicator of this investment's attractiveness**.** Examining the annual financial cash flows of cost savings from the investment in upgrading the RO plant reveals that the payback period in PV terms is less than two years. This is a significant saving, which is attributable, mainly, to the improved efficiency in wastewater and electricity that is acquired due to the implementation of improved pumping and RO membrane technologies.

The levelized financial cost of each cost component for producing an average of 2,042,670 m3 of clean water is estimated through using Equation 4. The total PVs of each cost component—in Table 3, rows 2 through 10—are divided by the PV of the produced water in Table 3, row 1, in order to arrive at the levelized financial costs (Table 4).

Table 4. Levelized financial costs of 2,042,670 m^3 of clean water in 2022 prices, USD/m^3.

Row no.		**New plant**	**Current plant**
	Capacity utilization (%)	52.85	75
1	Payment to municipality	0.133	0.232
2	Electricity cost	0.332	0.627
3	Chemical cost	0.003	0.006
4	**Total variable cost**	**0.468**	**0.865**
5	Fixed O&M cost	0.1	0.098
5	Initial capital cost	0.144	0.087
7	Recurrent capital cost	0.099	0.117
8	**Total fixed cost**	**0.344**	**0.302**
9	Levelized cost of water	**0.812**	**1.167**

Compared to the new technology plant, the levelized cost would be 0.812 USD/m^3 with the new technology, as opposed to 1.167 USD/m^3 with the current plant (Table 4, row 9). The levelized variable costs of the upgraded plant are much lower than those of the existing plant (Table 4, row 4). To produce the same amount of clean water, the payment to the municipality for purchasing the treated wastewater input to the new plant is 57% less than the old one (Table 4, row 1). Additionally, the electricity cost is 53% lower in the new plant than in the existing plant (Table 4, row 2).

4.1.2. Case II: New Technology Producing the Same Amount of Water as the Existing Plant when Operating at 100% Capacity

In the second scenario, the two plants are compared based on producing the same amount of water over their lifetimes while the existing plant is operating at 100% of its capacity.

To produce the same amount of water as the full operational capacity of the existing Levent Plant (20 hours per day), the new plant must run at 70.47% of its capacity (on average, 16.89 hours per day). In this scenario, throughout the project's 20-year lifetime, both plants would produce, in PV terms, approximately 2,723,550 m^3 of water (Table 5, row 1).

Table 5. Present value of financial output and costs in terms of equal production in the two plants, in 2022 prices.

Row no.		**New plant**	**Current plant**	**Change in cost**
	Capacity utilization (%)	70.47	100	
1	Quantity of water produced ('000) m^3	2,723.55	2,723.55	
2	Total payment for wastewater ('000) USD	363.14	630.72	267.58
3	Total electricity cost ('000) USD	902.05	1,699.41	797.36

4	Total chemical cost ('000) USD	8.31	15.89	7.58
5	Total variable cost ('000) USD	1,273.50	2,346.02	1,072.52
6	Total fixed O&M expenditures ('000) USD	203.83	196.7	−7.13
7	Total initial capital costs ('000) USD	294.69	177.93*	−116.76
8	Total recurrent capital costs ('000) USD	236.9	278.97	42.07
9	Total fixed cost ('000) USD	735.42	653.60	−81.82
10	Total lifetime financial costs ('000) USD	2,008.92	2,999.62	990.7

* The initial capital cost of the old plant includes storage tanks, carbon filters, sand filters, pipelines, fittings, electricity installations, as well as land and building costs.

The PV of the total financial cost of the new technology plant, including the initial capital investment, is 67% of the total financial cost of the existing plant (Table 5, row 10). The electricity costs have been reduced to 53% of the existing plant. When switching from the current plant to the new technology, the NPV of the savings in 2022 prices over 20 years of operation would be USD 990,700—or 33% of the PV of the total financial cost of the old plant (Table 5, row 10).

According to Table 6 and Equation 4, the levelized cost of production of one cubic meter of clean water with this scenario would be USD 1.101 with the current plant, while it would be USD 0.738 with the new technology plant (Table 6, row 9). The levelized variable costs of the new plant are only 54% of the old plant's levelized variable costs (Table 6, row 4).

Table 6. Levelized financial costs of water produced when operating at different average levels of capacity in 2022 prices, USD/m^3.

Row no.		**New plant**	**Current plant**
	Capacity utilization (%)	70.47	100
1	Payment to municipality	0.133	0.232
2	Electricity cost	0.331	0.624
3	Chemical cost	0.003	0.006
4	**Total variable cost**	**0.468**	**0.861**
5	Fixed O&M cost	0.075	0.072
6	Initial capital cost	0.108	0.065
7	Recurrent capital cost	0.087	0.103
8	**Total fixed cost**	**0.27**	**0.24**
9	Levelized cost of water	0.738	1.101

4.1.3. Case III: Both Plants Operate at 100% of Their Capacity

If both plants operated at full capacity every day of the year, the old facility would generate 2,723,550 m^3 during its operational life. The new plant would produce 3,864,940 m^3 of clean water (Table 7, row 1). Throughout the plant's 20-year operating life, a total of 1.1 million m^3 of more high-quality water would be generated by the new facility than by the current one.

While producing 42% more water in the full-capacity operation of both plants, the total financial cost of the new technology plant is still only 87% of the total financial cost of the existing plant at full capacity (Table 7, row 10).

Despite producing a great deal of more water, the new plant's electricity usage and costs would still be reduced by 25% (Table 7, row 3).

Table 7. Present value of the financial output and costs in terms of equal production in the two plants, in 2022 prices.

Row no.		New plant	Current plant
	Capacity utilization (%)	100	100
1	Quantity of water produced ('000) m^3	3,864.94	2,723.55
2	Total payment for wastewater ('000) USD	515.33	630.72
3	Total electricity cost ('000) USD	1,277.22	1,699.41
4	Total chemical cost ('000) USD	11.79	15.89
5	Total variable cost ('000) USD	1,804.34	2,346.02
6	Total fixed O&M expenditures ('000) USD	201.61	196.7
7	Total initial capital costs ('000) USD	294.69	177.93*
8	Total recurrent capital costs ('000) USD	309.44	278.97
9	Total fixed cost ('000) USD	805.73	653.6
10	Total lifetime financial costs ('000) USD	2,610.07	2,999.62

* The initial capital cost of the old plant includes storage tanks, carbon filters, sand filters, pipelines, fittings, electricity installations, as well as land and building costs.

The first three rows in Table 8 are associated with variable costs for the two plants in a full-capacity operation. By upgrading the system, the amount of payment to the municipality for raw water will decrease from 0.232 USD/m^3 to 0.133 USD/m^3. The 10 cent/m3 reduction in the cost of input water use comes because of the improved technical efficiency of the system. This results in a 57% reduction in the payments to the municipality when operating with the new system compared to the old one (Table 8, row 1).

The electricity cost/m^3 of potable water production would decrease from 0.624 USD/m^3 to 0.33 USD/m^3 (Table 8, row 2). This is approximately a 53% reduction in electricity cost for the new system. Due to the electricity-intensive nature of the RO process, electricity savings are the most significant component in terms of reducing financial costs.

The chemical cost will decrease from 0.006 USD/m^3 to 0.003 USD/m^3, which is a 50% reduction (Table 8, row 3). These three components reduce the variable production costs from 0.861 USD/m^3 for the old plant to 0.467 USD/m^3 for the upgraded plant. The total variable cost of the new plant will only be 54% of the total variable cost of the old plant (Table 8, row 4).

The fixed O&M cost will drop from 0.072 USD/m^3 to 0.052 USD/m^3, a reduction of 28% (Table 8, row 5). The initial capital cost of the storage tanks, carbon filters, sand filters, pipelines, fittings, electricity installation, as well as the land and building costs are common to both systems. New investments will need to be made in the RO system, including the membranes and pressure pumps. The impact of these investments is to increase the levelized cost of the initial capital cost from 0.065 USD/m^3 to 0.076 USD/m^3 (Table 8, row 6). The recurrent capital cost of the old plant is 0.103 USD/m^3, which decreases to 0.080 USD/m^3 in the new plant (Table 8, row 7). After combining all these changes, the total fixed levelized cost of the old plant is 0.240 USD/m^3, while for the upgraded plant it is 0.208 USD/m^3 (Table 8, row 8).

The total levelized financial cost is the sum of the levelized variable and the levelized fixed costs of producing one cubic meter of clean water. The total financial levelized costs for the upgraded plant, if operating at full capacity, is 0.675 USD/m^3. When the existing plant operates at full capacity, its total financial levelized costs are 1.101 USD/m^3 (Table 8, row 9).

Table 8. Levelized financial costs of the water produced when operating at the full capacity of the two plants in 2022 prices, USD/m^3.

Row no.		New plant	Current plant
1	Capacity utilization (%)	100	100
2	Payment to municipality	0.133	0.232
3	Electricity cost	0.33	0.624
4	Chemical cost	0.003	0.006
5	**Total variable cost**	0.467	0.861
6	Fixed O&M cost	0.052	0.072
7	Initial capital cost	0.076	0.065
8	Recurrent capital cost	0.08	0.103
9	**Total fixed cost**	0.208	0.24
10	Levelized cost of water	0.675	1.101

In all these three scenarios, there is a strong financial incentive for the owner of the RO facility in question to invest in upgrading it. The analysis now explores the environmental and economic implications of upgrading this RO plant.

4.2. Economic Analysis

The financial analysis estimates how much it costs the private producers of the water to invest in and operate the RO plants. The private financial perspective does not consider the external costs and benefits, which could cause the economic costs to diverge from the financial ones [15]. There are two essential and significant externalities in this study. One is the economic opportunity cost of the treated wastewater, which is utilized as an input into the RO system and is substantially lower than the municipality's charge. The other is the health and damage costs of the pollution that is created by generating the electricity used to power the plants.

Less water will be available to recharge the aquifer when this facility uses the wastewater treated at the NWTP. The greater distance to the water table increases the expense for farmers to pump water from the aquifer. Even though this sum is insignificant, we consider it an externality for both plants. The environmental costs of the concentrated effluents discharged from the RO plant are usually a significant negative environmental externality of such RO operations. However, for this particular RO plant, this source of environmental cost is insignificant. This is because the amount of wastewater purchased for use as an input to the RO plant represents only 3% of the total amount of wastewater produced by the NWTP. The concentrated effluents from the plant are returned to the discharge canal of the NWTP, and are to be mixed with the rest of the treated wastewater being discharged from the plant. In this process, the effluents are considerably diluted before recharging the aquifer.

4.3. Emission Costs

A very serious negative externality from the operation of the RO plant is caused by the additional electricity generation that is required to operate such plants. The reduction in emissions is a significant source of economic benefits that are obtained from upgrading the plant because of its lower electricity requirements. It is also a significant determinant of the health impacts on the local and worldwide population because of the reduced level of emissions.

In North Cyprus, high levels of local pollution are produced through the use of heavy fuel oil to run two steam turbines, as well as due to a number of large diesel generators that are operated without the employment of pollution filters. On the island, the power generators are close in proximity to some of the most densely populated areas and also the more famous tourist destinations. One of the highest economic costs of this wastewater reuse through RO processing is the additional costs that are imposed on individuals' and the communities' health due to the increased emissions that occur due to the required increase in electricity generation.

There are two categories of emission components. First, certain pollutants affect the health and physical resources of local communities. Sulfur dioxide, nitrogen oxides, particulate matter (2.5 μm and smaller), particulate matter (10 μm), and non-methane organic compounds (NMVOCs) are local emissions (Table 9, rows 1 to

5). Then, there are GHGs impacting the global environment. These include methane, carbon dioxide, and carbon monoxide emissions (Table 9, rows 6 to 8).

Table 9. The environmental emission costs and economic costs of the pollutants of the diesel fuel generators.

Row no.	Pollutants from electricity generation by heavy fuel oil		kg/MMBtu	USD/kg emission costs (2022 prices)
1	Volatile organic compounds	NMVOC	0.04	−0.51[1]
2	Nitrogen oxides	NOx	0.86	8.8[2]
3	Particulate matter	PM10	0.03	10.45
4	Ultra-fine particulate matter	PM2.5	0.02	67.61[3]
5	Sulfur dioxide	SO_2	0.46	9.94
6	Carbon dioxide	CO_2	74.84	0.07
7	Carbon monoxide	CO	0.39	0.05
8	Methane	CH_4	0.004	0.86

Note[1]: The negative value for NMVOC emissions in Cyprus is related to the fact that NOx is the primary precursor of ozone in Cyprus and that emissions of NMVOC tend to lower ozone concentrations.

Notes [2] and [3]: A total of 66.8% of Cyprus' population live in cities. As such, for the purposes of calculating these two values, we used 66.8% of the pollutant in urban areas and 33.2% in rural areas.

Source Column 1: [23]. Source Column 2: [24].

In this study, a quantitative estimation is made in monetary terms of the local health costs inflicted on the population of Cyprus, as well as the costs of the GHGs that are inflicted on the global population as a result of generating electricity for the RO plants. These estimates are made by estimating the kgs of each pollutant that is emitted per MWh, using the parameter values for the type of generation plants and the fuel used to generate electricity in North Cyprus. After estimating the kgs of each type that are produced by the additional electricity generation, a set of health and damage factors are applied to each of these quantitative factors in order to estimate the resulting health costs and the GHG damage that is created by the operation of the RO plants. Table 9, column 2, reports each pollutant's estimated damage cost in US dollars per kilogram.

The following section of this paper describes the steps for evaluating the emission costs in detail.

4.3.1. Steps for the Estimation of Emission Costs

1. Calculate the annual electricity consumption of the RO plant;
2. Estimate the total MMBtu (million British thermal units) of the fuel required to generate this electricity. This is a standard measure of the amount of heat energy produced on the combustion of 1 kg of fuel;
3. Estimate the quantities of pollutants emitted per MMBtu through generating this quantity of electricity when using the types of plants that are employed in North Cyprus. These air pollutant emission factors, by generator type, are obtained from the United States Environmental Protection Agency [23] (Table 9, col. 1);
4. The cost of the damage inflicted on North and South Cyprus arises from an increased health impact (morbidity and mortality) and property damage. Estimates are provided by the EU for North and South Cyprus, and are combined for each pollutant that is produced by North Cyprus' electricity generation [24] (Table 9, col. 2). These values have been adjusted to 2022 prices;
5. The kgs of emissions, by type, are then multiplied by their social costs per kg to estimate the monetary values of the damage inflicted each year. In addition, the PVs of these emission costs are calculated over the plant's lifetime.

4.3.2. Case I: Both Plants Produce the Same Amount of Water as is Currently Being Produced by the Existing Plant (75% Utilization Rate)

The PVs of these emission costs over the plant's lifetime are reported in Table 10. It is presumed that North and South Cyprus communities share all local environmental costs equally. While North Cyprus has a population of approximately 25% of the size of the population of South Cyprus, its generation plants are located very close to some of the most populated areas of North Cyprus.

Table 10. Present value at 8% of the emission costs in terms of equal production in the two plants, ('000) USD.

Row no.	PV of the quantity of water over 20 years 2,042.672 ('000) m^3	New plant	Current plant
	Capacity utilization (%)	52.85	75
	Local emission		
1	Economic cost of NMVOC emissions	60.9	127.69
2	Economic cost of nitrogen oxide emissions	101.41	212.64
3	Economic cost of particulate matter (10µm) emissions	3.63	7.62
4	Economic cost of particulate matter (2.5µm) emissions	16.38	34.34
5	Economic cost of sulfur dioxide emissions	−0.25	−0.53
6	Subtotal of local economic cost	182.06	381.75
	Global emission		
7	Economic cost of carbon dioxide emissions	72.7	152.44
8	Economic cost of carbon monoxide emissions	0.25	0.53
9	Economic cost of methane emission	0.04	0.09
10	Subtotal of global economic cost	72.99	153.06
11	Economic cost of emission in North Cyprus	91.03	190.87
12	Economic cost of emission in all of Cyprus	182.06	381.75
13	Economic cost of GHGs	72.99	153.06
14	Total economic cost of emissions for electricity production	255.06	534.8

The economic cost of the water that is produced by the plant and the levelized economic costs, excluding and including the cost of pollution emissions borne by the specific stakeholders, are defined in the following two tables for the case where the capacity operation of the Levent Plant is 75%. The PVs of each economic cost of each plant are estimated using equations 5–8, and the results have been discounted back 8% to 2022 prices.

The costs associated with North and South Cyprus' health damage are equivalent to 30% of the financial cost of the electricity that is consumed by the existing RO plant when it operates at 75% of its potential capacity. For the upgraded plant, in terms of producing the same amount of water, the health costs imposed on North and South Cyprus are equal to 27% of the electricity costs. Considering only North Cyprus, the local health costs are equal to 15% of the electricity that is used to produce water by the current RO plant, and 13.5% for the new plant. Evaluating the costs of electricity generation emissions from the global perspective, by including the social costs of GHGs, the total emission costs equal 42% of the cost of electricity that is used to produce water by the existing RO plant and 38% by the new plant.

The PV of each of the economic cost components over the lifetime of the facility is presented in Table 11, column 1, for the new technology plant; in column 2, the PVs of the same components of economic costs are presented for a level of water production that is equal to that produced by the existing plant operating at 75% capacity. The total variable economic cost of the upgraded plant, excluding the emissions costs, is only 54% of the current plant's variable cost of production (Table 11, row 4). Using equations 9–12, the PVs of the total economic costs are estimated from four different perspectives. The first case is where all the emission costs are excluded (Table 11, row 12). The second is where only the emission costs that are imposed on North Cyprus are included (Table 11, row 13). The third includes the emissions costs imposed on Cyprus (Table 11, row 14). The last case is when the estimated costs of all the emissions borne by Cyprus and the rest of the world are included (Table 11, row 15).

When considering the ratios of the total economic costs of production for the upgraded plant to those of the existing plant in these four cases, we find the values of these ratios are 0.72, 0.71, 0.69, and 0.67, respectively. The economic costs of the upgraded plant are 28% to 33% less than the existing plant, depending on whose perspective one considers. These savings arise primarily from a reduction in the quantity of wastewater purchased, a decline in the total electricity used, and a decrease in the amount of pollutant emissions due to a decrease in the required amount of electricity to be generated. The economic internal rate of return from the investment made to upgrade the system was found to be 72 percent.

Table 11. Present value at 8% of the total economic costs for different capacity utilizations with emissions, in USD ('000).

Row no.	PV of the quantity of water over 20 years 2,042.672 ('000) m^3	New plant	Current plant
	Capacity utilization (%)	52.85	75
1	Total economic opportunity cost of wastewater	20.43	20.427
2	Total economic cost of electricity	678.24	1,281.368
3	Total economic cost of chemicals	6.23	11.918
4	**Total variable cost**	704.9	1,313.71
5	Total economic cost of initial capital	294.69	177.93*
6	Total economic cost of recurrent capital cost	202.15	239.63
7	Total economic cost of fixed O&M	205.16	199.18
8	**Total fixed cost**	701.99	616.74
9	Total cost North Cyprus' emissions cost	91.03	190.87
10	Total cost all of Cyprus' emissions cost	182.06	381.75
11	Total cost GHG emission	72.99	153.06
12	Total economic cost of water (without pollution)	1,406.89	1,930.46
13	Total economic cost of water (North Cyprus' emissions)	1,497.92	2,121.33
14	Total economic cost of water (all of Cyprus' emissions)	1,588.96	2,312.20
15	Total economic cost of water (local and global emissions)	1,661.95	2,465.26

* The initial capital cost of the old plant includes storage tanks, carbon filters, sand filters, pipelines fittings, electricity installations, as well as land and building costs.

These PVs of the economic costs—as are presented in Table 11—when divided by the PVs of the water produced (Table 3, row 1), yield the required levelized economic costs of producing water by these RO plants from the perspective of the residents of North Cyprus, Cyprus generally, and globally (equations 13–16). The results are reported in Table 12. The first three variables in this table are the economic variable costs of the facilities, including the levelized economic opportunity cost of wastewater (row 1), the levelized economic electricity cost (row 2), and the levelized economic chemical cost (row 3).

If the RO plant did not use the water, more water would recharge the aquifer, raising the water table. The economic opportunity cost of using the wastewater in the RO plant is the additional pumping costs the farmers will incur from having less water in the aquifer. This cost is approximately 0.01 USD/m^3 (Table 12, row 1).

Table 12. Levelized economic costs (with diesel fuel generators) for the different levels of utilization (in 2022 prices), USD/m^3.

Row no.	PV of the quantity of water over 20 years 2,042.672 ('000) m^3	New plant	Current plant
	Capacity utilization (%)	52.85	75
1	Levelized economic opportunity cost of wastewater	0.01	0.01
2	Levelized economic electricity cost	0.332	0.627
3	Levelized economic chemical cost	0.003	0.006
4	**Total levelized variable cost**	0.345	0.643
5	Levelized economic initial capital cost	0.144	0.087
6	Levelized economic recurrent capital cost	0.099	0.117
7	Levelized economic fixed O&M cost	0.1	0.098
8	**Total levelized fixed cost**	0.344	0.302
9	Levelized cost of North Cyprus' emissions	0.045	0.093

10	Levelized cost of all of Cyprus' emissions	0.089	0.187
11	Levelized cost of GHG emissions	0.036	0.075
12	Levelized economic cost of water (without pollution)	0.689	0.945
13	Levelized economic cost of water (North Cyprus' emissions)	0.733	1.039
14	Levelized economic cost of water (all of Cyprus' emissions)	0.778	1.132
15	Levelized economic cost of water (global emissions)	0.814	1.207

Without accounting for the costs associated with emissions, the upgraded plant's levelized economic costs decreased to 0.689 USD/m³ from 0.945 USD/m³ (Table 11, row 12). From the perspective of North Cyprus, the levelized economic cost decreased from 1.039 USD/m³ to 0.733 USD/m³ (Table 11, row 15). Moreover, from a global perspective, it decreased from 1.207 USD/m³ to 0.814 USD/m³ (Table 11, row 15).

From this analysis, it is clear that particularly substantial economic and environmental benefits can be realized from the timely upgrading of the RO technology, even when electricity is being generated in a manner that creates a great deal of harmful pollution.

4.3.3. Case II: New Technology Producing the Same Amount of Water as the Existing Plant when Operating at 100% Capacity

In this context, both plants produce the same amount of water, with the existing plant operating at full capacity and the new technology facility operating at 70.47% capacity. In this scenario, approximately 33% more water is produced than in the previous case.

Using equations 9–12, the PVs of the total economic costs are estimated from four different perspectives. The first case is where all the emission costs are excluded (Table 13, row 12). The second case is where only the emission costs that are imposed on North Cyprus are included (Table 13, row 13). The third case includes the emission costs that are imposed on Cyprus generally (Table 13, row 14). The last case is when the estimated costs of all the emissions borne by Cyprus and globally are included (Table 13, row 15). Calculating the ratios of the total economic costs of production for the upgraded plant to those of the existing plant in these four cases, we find the values of these ratios are 0.69, 0.67, 0.66, and 0.65, respectively. The economic costs of the upgraded plant are 31% to 35% less than those of the existing plant, depending on whose perspective one considers. Again, these savings arise primarily from the decrease in the amount of wastewater purchased, the decrease in the consumption of electricity, and the lower level of harmful emissions that are incurred because of the reduction in the quantity of electricity that needs to be generated.

Table 13. Present value at 8% of the total economic costs for different capacity utilization levels with heavy fuel oil emissions, in USD ('000).

Row no.	**PV of the quantity of water over 20 years 2,723.55 ('000) m³**	**New plant**	**Current plant**
	Capacity utilization (%)	70.47	100
1	Total economic opportunity cost of wastewater	27.24	27.24
2	Total economic cost of electricity	902.05	1,699.41
3	Total economic cost of chemical	8.31	15.89
4	**Total variable cost**	937.6	1,742.53
5	Total economic cost of initial capital	294.69	177.93
6	Total economic cost of recurrent capital cost	236.9	278.97
7	Total economic cost of fixed O&M	203.83	196.7
8	**Total fixed cost**	735.42	653.6
9	Total cost North Cyprus' emissions	121.07	253.28
10	Total cost all of Cyprus' emissions	242.14	506.56
11	Total cost GHG emission	97.08	203.09
12	Total economic cost of water (without pollution)	1,673.01	2,396.13
13	Total economic cost of water (North Cyprus' emissions)	1,794.08	2,661.58
14	Total economic cost of water (all of Cyprus' emissions)	1,915.15	2,902.69
15	Total economic cost of water (local and global emissions)	2,012.23	3,105.79

* The initial capital cost of the old plant includes storage tanks, carbon filters, sand filters, pipelines, fittings, electricity installations, as well as land and building costs.

In this instance, the levelized economic costs of producing water by these two RO plants from the perspective of the residents of North Cyprus, the entire island of Cyprus, and globally were created by dividing the PVs of the economic costs by the PVs of the water produced (Table 5, row 1). The levelized economic costs are estimated using these values and equations 13–16. The results are reported in Table 14.

Without accounting for the cost of emissions, the renovated plant's levelized economic costs decreased to 0.614 USD/m^3 from 0.880 USD/m^3 (Table 14, row 12). For North Cyprus, the levelized economic cost has decreased from 0.973 USD/m^3 to 0.659 USD/m^3 (Table 14, row 13) and, from a global perspective (Table 14, row 15), the levelized cost has decreased from 1.140 USD/m^3 to 0.739 USD/m^3.

Table 14. Levelized economic costs (with diesel fuel generators) for the different levels of utilization (in 2022 prices), USD/m^3.

Row no.	PV of the quantity of water over 20 years 2,723.55 ('000) m^3	New plant	Current plant
	Capacity utilization (%)	70.47	100
1	Levelized economic opportunity cost of wastewater	0.01	0.01
2	Levelized economic electricity cost	0.331	0.624
3	Levelized economic chemical cost	0.003	0.006
4	**Total levelized variable cost**	0.344	0.64
5	Levelized economic initial capital cost	0.108	0.065
6	Levelized economic recurrent capital cost	0.087	0.102
7	Levelized economic fixed O&M cost	0.075	0.072
8	**Total levelized fixed cost**	0.27	0.24
9	Levelized cost of North Cyprus emissions	0.044	0.093
10	Levelized cost of all of Cyprus emissions	0.089	0.186
11	Levelized cost of GHG emissions	0.036	0.075
12	Levelized economic cost of water (without pollution)	0.614	0.88
13	Levelized economic cost of water (North Cyprus' emissions)	0.659	0.973
14	Levelized economic cost of water (all of Cyprus' emissions)	0.703	1.066
15	Levelized economic cost of water (global emissions)	0.739	1.14

In Table 15, using equations 17–21, the NPVs of the investments to improve the RO facility are estimated from each stakeholder's financial and economic perspectives for the two scenarios. As was shown in Tables 3 and 5, the financial NPV of upgrading to new technology in the first scenario with the two plants producing a PV of 2,042,670 m^3 is USD 724,240. In the second scenario, when producing 2,723,550 m^3, the NPV is USD 990,700 (Table 15, row 1). From a financial perspective, this is a highly profitable investment and the financial NPV increases as the total amount of water required increases.

When an analysis is carried out from the economic perspective, we find it is also significant.

The net economic benefits without considering the emission costs are USD 523,570 in scenario one and USD 723,120 in scenario two (Table 15, row 2). When considering the NPV of the economic cost, three cases with three different definitions of whose benefits count would be defined. If we consider the case where only the benefits of North Cyprus' residents count, the net economic savings of upgrading are USD 623,410 for scenario one and USD 867,500 for scenario two (Table 15, row 3). In this case, the economic NPVs are very positive; however, they are not as large as the NPVs from the financial perspective.

When all the benefits enjoyed by the entire island of Cyprus (South and North) are counted, the net economic benefits of switching to modern technology are USD 723,240 in scenario one and USD 987,540 in scenario two (Table 15, row 4). In this case, the economic NPV is positive and almost equal to the NPV from the financial perspective. The NPVs of GHG emissions are USD 106,010 in scenario one and USD 80,070 in scenario 2 (Table 15, row 5). In the third assessment of the economic NPVs, all the savings from reduced pollution emissions are counted as economic benefits, including local (row 4) and GHG emissions (row 5). In this case, the NPV of the economic analysis is USD 803,310 for the first scenario and USD 1,093,560 for the second scenario (Table 15, row 6). From this global perspective, the net economic benefits exceed the NPV from the financial perspective in both scenarios. From both a financial and an economic perspective, this is a very worthwhile investment. In all situations, the NPV is positive from the economic point of view.

Table 15. The NPVs of investing into the new technology with 20 years of operation (in 2022 prices), ('000) USD.

Row no.	PV quantity of water produced over 20 years ('000) m^3	2,042.67	2,723.55
1	NPV of financial savings	724.24	990.7
2	NPV of the economic cost of water (without pollution)	523.57	723.12
3	NPV of the economic cost of water (North Cyprus' emissions)	623.41	867.5
4	NPV of the economic cost of water (all of Cyprus' emissions)	723.24	987.54
5	NPV of the economic cost of water (greenhouse gases)	80.07	106.01
6	NPV of the economic cost of water (local and global emissions)	803.31	1,093.56

5. Quantified Stakeholder Impacts on Water Risk Mitigation

According to the fundamental principle of distributive analysis, the economic PV of a set of variables is equal to the financial PV of those variables plus the PV of the total of the project's externalities. The values of these externalities are the distributive impacts [25]. This relationship is expressed in Equation 22:

$$NPV^{\text{economic}}_{t=0} = NPV^{\text{financial}}_{t=0} + \sum i\ PV^{\text{externalities}}_{t=0,\ i} \tag{22}$$

Table 16 presents the net stakeholder impacts of this project in two scenarios. In column 1, both plants produce, in PV, a total of 2,042,670 m^3 freshwater. In column 2, both plants produce, in PV, a total of 2,723,550 m^3 freshwater.

The new technology uses much less wastewater as an input and requires less electricity. Due to the lower use of electricity, the pollution costs are much lower. Much less wastewater must be purchased from the municipality, and the financial payments will be reduced. Although the values of the individual externalities are substantial, the total economic costs are very close to the total financial costs. According to Equation 22, the net stakeholder impact is the subtraction of the financial NPV from the economic NPV of USD 79,090 in scenario one and USD 102,850 in scenario two (Table 16, row 3).

Table 16. Stakeholder analysis of the investment to upgrade the RO plant, in 2022 prices ('000) USD.

Row no.	PV of the quantity of water produced over 20 years ('000) m^3	2,042.67	2,723.55
1	NPV of economic costs	803.31	1,093.56
2	NPV of financial costs	724.25	990.7
3	PV of the sum of net stakeholder impacts (rows 1–2)	79.06	102.85
	Stakeholders		
4	PV economic benefit of less emissions for the residents of North Cyprus	99.84	132.21
5	PV economic benefit of less emissions for the residents of South Cyprus	99.84	132.21
6	PV economic benefit of fewer GHGs	80.07	106.01

7	PV of savings on payments to the municipality for wastewater	200.68	267.58
8	PV of net stakeholder impacts (rows 4+5+6−7)	79.06	102.85

In the stakeholder analysis, it is clear that the private owner of the plant is the largest net beneficiary of this investment. In addition, because of this project's positive impact on the environment through reduced pollution, three groups will benefit significantly, namely the residents of North Cyprus, those of South Cyprus, and the entire globe due to the reduced GHG emissions (Table 16, rows 4, 5, and 6). At the same time, the reduced value of the purchases of treated wastewater is an offset to the economic benefits of the reduced pollution, as it is recorded as a financial cost; still, it is not an economical cost to the country. The Nicosia municipality collected the tax by charging for the treated wastewater.

6. Conclusions

This study highlights how crucial it is for water services to be technologically advanced, economically efficient, reliable, and sustainable. Moreover, it illustrates how developing the RO technique in producing freshwater from wastewater is a successful strategy for reducing the risks of water shortages in an urban water supply system.

The shortage of potable water and the increased risks of water shortages caused by climate change means that many water supply systems will need to rely increasingly on the RO treatment of wastewater and seawater to meet their needs for potable water. The utilization of wastewater recycling has a great deal of potential to reduce the cost of water that is produced by RO systems (Park 2020).

One way to mitigate the demand for electricity and the environmental damage caused by using RO systems is to ensure that these systems utilize the most economically efficient membrane and pumping technologies. Modernizing RO systems with the most advanced technology will provide various financial and economic benefits. As the system's operator, the private sector receives significant net financial benefits. Additionally, as the cost of electricity is typically the most crucial factor determining the costs of water production that is produced by RO, societies benefit significantly from the considerable savings that are associated with reduced electricity consumption, which leads to reduced emissions of air pollutants to the local and global environment.

The upgraded system is more sustainable because less wastewater is required to produce more freshwater, which results in both lower reimbursements to the municipality, a better allocation of the treated wastewater, less electricity utilized, as well as lower financial and economic costs. These lower costs reduce the price of water that is produced in the price range where it can compete with other water supply sources and where customers are willing to pay.

In this analysis, considering the current capacity of the existing plant and producing an equal amount of water of 2,042,670 m3, one cubic meter of freshwater production costs USD 1.167 for the existing plant and USD 0.812 for the upgraded plant. Expecting the water demand for the community to increase, in the case of each plant producing an equal amount of water of 2,723,550 m3 over its lifetime, the levelized cost would be USD 0.739 for the existing plant, and USD 1.140 for the new technology plant.

Currently the emissions of GHGs and their impact on global warming are of great concern to many governments. Often HFO or coal is used to generate electricity that produces significant amounts of GHG and local pollution. The local pollution results in serious health burdens. Consequently, substantial investments are being made to conserve electricity and to employ renewable electricity generation technologies. These options are expensive and have tended to raise the cost of electricity services. In many water-stressed countries substantial investments have already been made in RO facilities that are now technologically obsolete. The findings of this research indicate that there are potentially significant improvements in terms of the environment and the health of residents if such RO plants were technologically upgraded. If such plants are to be operated in an economically efficient manner, there is a need for continuous oversight by the authorities who are responsible for the water supply systems. As shown in this study, the upgrading of RO technologies has the potential to be financially beneficial to the owner of the facility through the reduction in electricity consumption and the increased efficiency of the operating system. This directly reduces the economic costs of the water that is supplied while decreasing the emissions of GHGs and pollutants that damage the health of local residents. Before undertaking costly solutions to mitigate GHG emissions, the authorities need to consider the possibility of undertaking certain upgrades of their existing RO facilities that produce potable water.

In summary, in the context of the challenges facing the world to reduce GHG emissions, the upgrading of energy-intensive systems to operate more efficiently can be a powerful way to reduce GHG emissions while also realizing a financially profitable investment. In addition, when electricity is generated in a manner that creates substantial local pollution, the health benefits to the residents are a significant component of the economic benefits of the upgrading investments.

Appendix A.

Table A1. Data used in this article.

Data	New technology	Current plant
Construction duration (years)	1	1
Operations duration (years)	20	20
Liquidation year (years)	21	21
Replacement of carbon filters	Every 3 years	Every 3 years
Replacement of membranes	Every 3 years*	Every 3 years*
Pump replacement	Every 10 years	Every 10 years
Cartridge filter replacement	Every 2 months	Every 6 months
Lifetime of a water storage tank	40 years	40 years
Lifetime of building	50 years	50 years
Wastewater intake pump installations		
Number of wastewater intake pumps in operation	1	1
Number of working hours per day	23.97 hours	20 hours
Cost per wastewater intake pump (USD)	6,500	6,500
Concrete storage to membrane pump installations		
Number of concrete storages to membrane pumps	1	1
Number of working hours per day	1 -23.97 hours	1 -20 hours
Cost per pump for concrete storage to membrane (USD)	3,117	3,117
High-pressure pump installations		
Number of high-pressure pumps in operation	1	2
Number of working hours per day	1 -23.97 hours	1 -20 hours
Cost per high-pressure pump (USD)	8,989	12,000
Membrane backwash pump installations		
Number of membrane backwash pumps	1	1
Number of working hours per day	0.03 hours	4 hours
Cost of membrane backwash pumps (USD)	512	512
Product transfer pump installations		
Number of product transfer pumps in operation	1	1
Number of working hours per day	1 -23.97 hours	1 -20 hours
Cost per transfer pump (USD)	3,080	3,080
RO membrane installations		
Number of RO membranes	60	60
Cost per RO membrane (USD)	1,200	1,000
Cost of installation of RO (USD)	72,000	60,000
Filters		
Cartridge filter installations		
Number of filters	22	3
Cost per filter (USD)	25	200
Sand filter installations		

Data	New technology	Current plant
Number of filters	2	2
Cost per filter (USD)	11,425	11,425
Carbon filter installations		
Number of filters	2	2
Cost per filter	13,360	13,360
Storage tank		
Number of storage tanks (250 m^3)	2	2
Cost per tank (USD)	18,000	18,000
CIP installation	7,593	0

*Plants are assumed to be operating at 100% capacity.

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