OECONOMIA
COPERNICANA

VOLUME 14 ISSUE 1 MARCH 2023

p-ISSN 2083-1277, e-ISSN 2353-1827
www.oeconomia.pl

ORIGINAL ARTICLE

Citation: López-Serrano, M. J., Lakho, F. H., Van Hulle, S. W. H., & Batlles-delaFuente, A. (2023). Life cycle cost assessment and economic analysis of a decentralized wastewater treatment to achieve water sustainability within the framework of circular economy. *Oeconomia Copernicana, 14*(1), 103–133. doi: 10.24136/oc.2023.003

Contact to corresponding author: María J. López-Serrano, mjlopezserrano@ual.es

Article history: Received: 17.11.2022; Accepted: 7.03.2023; Published online: 25.03.2023

María J. López-Serrano
University of Almería, Spain
orcid.org/0000-0001-6439-0819

Fida Hussain Lakho
Ghent University Campus Kortrijk, Belgium
orcid.org/0000-0001-8559-3981

Stijn W.H. Van Hulle
Ghent University Campus Kortrijk, Belgium
orcid.org/0000-0001-5773-7773

Ana Batlles-delaFuente
University of Almería, Spain
orcid.org/0000-0003-2108-0516

Life cycle cost assessment and economic analysis of a decentralized wastewater treatment to achieve water sustainability within the framework of circular economy

JEL Classification: *Q25; Q53; Q56*

Keywords: *wastewater; economic analysis; LCCA; Sustainable Development Goals; monetary evaluation*

Abstract

Research background: The increasing water demand together with an unceasing production of wastewater worldwide has resulted in a situation where the scarcity and pollution of water resources are jeopardizing and depleting such a vital asset.
Purpose of the article: In this context, Nature Based Solutions (NBS) such as Vertical Flow Constructed Wetlands (VFCWs) are key because of their capacity of channelling a waste into a resource. However, and notwithstanding their essential role, their financial benefits too often go unnoticed because of missing research that study them from an economic perspective and this article has covered this existing gap. The objective of this research is to analyse the economic consequences of using VFCW against its traditional alternative through a comprehensive economic assessment.
Methods: After doing a Life Cycle Assessment (LCA), a combination of two approaches has been carried out. This research has developed a holistic approach where a Life Cycle Cost Assessment (LCCA) based on a Cost Benefit Analysis (CBA) along with an economic evaluation of cleaning environmental costs have been calculated for two different scenarios. For this monetary analysis, the environmental externalities derived from the use of cleaning the pollution caused by a public water supply and sewerage system and the VFCW have been quantified.
Findings & value added: Results conclude that VFCW apart of being a cost-effective and profitable alternative for an investor, it has also valuable benefits for the society in general because of its meaningful and positive externalities and the high removal cost of the environmental pollutants of the traditional water supply and sewage system both contributing directly to the achievement of Sustainable Development Goals (SDGs). Furthermore, 4/5 environmental impacts derived from the use of traditional alternative pollute more than twice as much as the VFCW does. Lastly, the cleaning costs difference between both alternatives is 1,984,335€.

Introduction

The demand of the essential, valuable, unfairly-distributed and limited resource, freshwater, has been steadily increasing in the last decades and the situation is still expected to worsen further due to varying anthropic reasons, thus raising major concerns worldwide (Bunn, 2016; Tociu *et al.*, 2019; Ashu & Lee., 2021; Baggio *et al.*, 2021; Truchado *et al.*, 2021). Climate change, which comprises global warming and more unpredictable and changing weather patterns, along with the world's growing population, both forecasted to exacerbate in upcoming years, have derived into increased water scarcity and pollution which endangers the water supply and fair distribution of finite freshwater resources, putting strain on water and food security (Melián-Navarro & Ruiz-Canales, 2020; Al-agele *et al.*, 2021; Wang *et al.*, 2021; Arellano-Gonzalez *et al.*, 2021; Weerasooriya *et al.*, 2021; Maniam *et al.*, 2022). The envisaged worsening of a current fateful situation where more than two billion people experience water stress and four billion suffer from severe water scarcity for at least a month every year, bring to light the urgency of looking for alternative and sustainable water resources (UNESCO, 2021; UNESCO, 2022).

Within this context, treated wastewater has become into a reliable and cost-effective water alternative that guarantees water supply and that has been proved to be able to address many of the problems derived by water constraints all at once (Hristov *et al*., 2021). The use of reclaimed water is also of major importance in the pursuit of the 17 SDGs proposed by the United Nations (UN) in 2015, since it directly encompasses the aims of Goal 6 (clean water and sanitation for all) and favors the complete achievement of many other goals due to interconnections (Brennan *et al*., 2021; Di Vaio *et al*., 2021; Rodríguez de Sá Silva *et al*., 2022). The already proven key role of treated wastewater is particularly critical in developing countries where data shows devastating consequences from not having an adequate water supply or wastewater management, resulting in the population being seriously affected in terms of hygiene, health, the economy, and socially (Lutterbeck *et al*., 2017; Sánchez Pérez *et al*., 2020). This alternative source of water channels waste into a resource, thus collaborating with circular economy and enhancing sustainable development without jeopardizing the environment, and preventing the degradation of ecosystems (Lavrnić *et al*., 2017; Makropoulos *et al*., 2018; Pahl-Wostl, 2019; Ponce-Robles *et al*., 2020; Estelrich *et al*., 2021).

Against this background, the objective of this research is to analyse the economic consequences of using NBS against its traditional alternative through a comprehensive economic assessment able to show not only the financial profitability of the investment but also the treatment costs saved by implementing its use. This objective is key in order to show law makers, stakeholders and researchers in a measurable way the importance of investing in NBS to reach water sustainability within the framework of circular economy. Furthermore, by reaching the objective proposed, the pivotal role that both treating wastewater properly and channelling waste into resource have in view of the SDGs will be unveiled in a quantifiable way. For this purpose, prior to this research, a LCA following ISO 14044 was carried out where environmental impacts were evaluated and quantified in the same scenario here considered.

This paper consists of a quantitative analysis that not only considers traditional financial indicators widely extended in economic evaluations in water-related analysis through a LCCA to see the profitability of the investment but also carries out a monetary evaluation of the cleaning costs derived from the use of NBS against the traditional alternative. For developing these ambitious methodologies, a combination two different approaches, which make this groundbreaking research holistic, have been taken. On the one hand, traditional financial indicators widely extended in economic evaluations in water-related analysis have been calculated in a LCCA through CBA. The decision criteria used to assess CBA are Net Present Value (NPV), Benefit-Cost Ratio (BCR), Internal Rate of Return (IRR) and Discounted Payback Period (DPP). On the other hand, a monetary evaluation of the cleaning cost of environmental indicators derived from the use of both scenarios considered, the traditional and the constructed wetland (CW), have been carried out thus truly evaluating and quantifying the real costs of both alternatives.

Literature review

The increasing water demand together along with the climate change and the unceasing production of wastewater worldwide, has led to a scenario where water resources are depleting and has resulted in a situation where reusing wastewater is not only an adaptive action but also a feasible solution to achieving sustainable development (Hejduková & Kureková, 2020; Zagklis & Bampos, 2022). Against the current situation, the importance of channelling waste into a new resource as reclaimed water is of fundamental importance, since it fosters circular economy and sustainability goals. Furthermore, it is important to analyse the potential environmental impacts derived from these alternative treatment systems (Resende *et al.*, 2019). The use of these green systems is steadily increasing and anticipated to grow in both developed and developing countries, because of the positive reduction they may enhance of energy demand, environmental pollution and economic costs (Nuamah *et al.*, 2020).

While traditionally wastewater treatment systems have been centralized, for various reasons, such as their great capacity to transport large volumes of water, benefits of scale and their highly predictable treatment performance, their high economic cost and energy and resources consumption are leaving room for decentralized systems (Hasik *et al.*, 2016; Peñacoba-Antona *et al.*, 2021; Khalkhali *et al.*, 2021). Decentralized systems are typically standalone system used for smaller wastewater flows where the reuse happens on site (Licciardello *et al.*, 2018; Van de Walle *et al.*, 2022). Energy consumption plays a crucial role within the "water-energy" nexus with large countries like the US spending over 45% of total primary energy on "energy for water", which includes every process where water needs energy and water supply systems representing up to 15% of total energy usages (Kyle *et al.*, 2016 Vakilifard *et al.*, 2018,). Another limitation of Centralized Water Recycling Systems (CWRS) is their incapacity to effectively and efficiently provide water resources to rural and low-income urban areas whether because of geographical dispersion or low water pressure and leaking pipes (Pickering *et al.*, 2015; Laitinen *et al.*, 2017; Wang *et al.*, 2019). This last disadvantage is of great importance as more than 40% of the global population live in rural areas (Welivita *et al.*, 2021; Balk *et al.*, 2021). Although fully centralized systems have been widely used in the last decades, the latest recommendations based on research and cost-benefit analyses suggest transitioning away from these systems towards more adaptable and sustainable ones, thus leading to a shift from conventional centralized systems to either hybrid or fully decentralized ones (Dev *et al.*, 2021; Castellar *et al.*, 2022). Decentralized Wastewater Treatment Systems (DWTS) have been shown to be a sustainable, viable, flexible, reliable, and cost-effective alternative source of water, especially useful on a small scale (Gukelberger *et al.*, 2019; Liu *et al.*, 2021; Maryati *et al.*, 2022). Furthermore, the use of DWRS, apart from enhancing environmental protection and resource recovery, may lead to environmental and local economic development (Jahne *et al.*, 2020; Van de Walle *et al.*, 2022; Estévez *et al.*, 2022).

One of the most extended and consolidated decentralized technologies are NBS such as CW, which, apart from strictly meeting chemical and physical standards for water reuse, require low energy, are cost-effective, easily operational and low maintenance (Corbella *et al.*, 2017; Ricart *et al.*, 2021; Cao *et al.*, 2021). Since the construction of the first CW in 1974, the technology of these artificial engineered wetlands has been developing to make them desirable and efficient in the task of treating wastewater physically, chemically, and biologically which has expanded their use and implementation worldwide (Zhang *et al.*, 2021). CWs are considered a green, nature based technology that involves wetland vegetation, soil substrates and microorganisms, and whereby metabolic processes take place resulting in the transformation and removal of pollutants from water (Gattringer *et al.*, 2016; Resende *et al.*, 2019). Furthermore, if planted, they can be aesthetically pleasing while promoting biodiversity, contributing to flood protection, and offering cooling effects (Dumax & Rozan, 2021). To strengthen the comparison with traditional wastewater plants, the fact that the greenhouse gas emissions (GHG) of a CW have proved to be 2714 times lower can be highlighted (Liu *et al*., 2019). Their high efficiency linked to important ecological benefits, make them green technology that promote a sustainable water supply (Cui *et al*., 2022). Fostering the construction of CWs thus improves the water supply from a sustainable point of view by meeting human needs without depleting existing water resources nor affecting in a negative way local economies and the environment in a negative way (Diao, 2021; Kataki *et al*., 2021).

Despite having been used for more than 50 years and all of the research stating the benefits of CWs, although there has been an increase in their popularity, their effective implementation still remains a challenge (Wu *et al*., 2015; Deng *et al*., 2021; Vymazal *et al*., 2021; Yang *et al*., 2022). This failing, which partially impedes a successful full adoption, might be a result of a lack of agreement on many specifities in the wastewater industry, concretely because environmental impacts studied in LCAs are highly dependent on many factors, such as the location, population, or socio-economic conditions, among others (Lourenço & Nunes, 2021). Despite the importance of reducing negative externalities and fostering ecosystem services, which deeply benefit the whole society with their positive externalities, all the intangible benefits of using VFCW too often go unnoticed because of missing economic evaluations and cost-analyses (Freeman *et al*., 2019). In a previous study of the current authors, a comparative LCA was conducted to assess the environmental impacts of a decentralized wastewater treatment system combining a VFCW and a membrane-based purification unit for treating black water for drinking purposes with their conventional alternative of sewage treatment and potable supply (Lakho *et al*., 2022). The outcomes of the study showed that the decentralized system had overall lower environmental impacts as compared to its conventional alternative. Against this background, there is an imperative need for research that shows economic data that verifies and supports not only the financial desirability of the investment but also the environmental benefits of using this alternative water supply against its traditional competitor from a tangible, comparable and monetary perspective. Furthermore, and in order to put an end to this problem, this study introduces a groundbreaking methodology where through holistic research, traditional financial indicators have been calculated along with the economic value of environmental indicators that may endanger human health and the environment and jeopardize ecosystem services. In this way and based on a previous LCA carried out, data variability from one geographical area to another would be mostly eliminated due to environmental indicators having almost the same human and environmental consequences worldwide, and so results can be representative and easily extrapolated to other areas (Lakho *et al*., 2022).

Research methods

Scenario

All the calculations of this research have been done considering a VFCW coupled with a membrane-based potable water production system as the investment proposal. This scenario, which has already gone through an LCA, is operated at a restaurant in Belgium with a water flow of 4 $m^3.d^{-1}$, and it has been compared with its traditional alternative: a public water supply and sewerage system in the same geographical area of Belgium which is ±300m away from the restaurant (Lakho *et al*., 2022). The restaurant is open 5 days a week and can serve a maximum of 135 customers per day. The expected discharge rate is ¼ population equivalent per customer (1/4 × 150 = 37.5 L). If it is considered that is going to be working fifty-two weeks per year and a period of twenty years, this means that the initial investment figures have been calculated for a VFCW that is going to be capable of treating 20,800m^3 of wastewater during its useful life. Figure 1 shows the different steps that water go through in both of the scenarios considered in this research, VFCW and conventional system.

Life cycle cost analysis

An LCCA was carried out in order to appraise the economic viability and efficiency of a CW used as an alternative to traditional sewerage system in a restaurant. LCCA is an analytical approach based on cost-benefit analysis (CBA) and its use to evaluate the profitability of an investment project is widely extended especially for alternative water supply systems like VFCW (Diaz-Elsayed *et al*., 2020; Cao *et al*., 2021). Through CBA, monetary value is assigned to each input and output that result from the project that is being evaluated. Nevertheless, and despite its key value in project evaluation, its use is rarely seen in methodologies related to wastewater reuse projects, leaving a research gap in this field of study (Declercq *et al*., 2020). The most common decision criteria used to assess cost-benefit analysis are NPV, BCR, IRR, DPP (Galvis *et al*., 2018; Omole *et al*., 2019; Freeman *et al*., 2019; Loarte-Flores *et al*., 2020; Pahunang *et al*., 2021; Sakcharoen *et al*., 2021; López-Serrano *et al*., 2021; Ghafourian *et al*., 2022). In the context of developing an LCCA this research is of great importance because a new factor related to the interest rate calculation has been introduced into the economic methodology. Although there is existing literature where traditional indicators have been calculated, in all of the papers previously published only a single fixed interest rate for the whole period has been considered, thus leaving behind the interest fluctuations that may happen in periods as long as 20 years (Abdulfatah *et al*., 2019; Otter *et al*., 2020). Furthermore, and in a context of uncertainty in the international financial markets where interest rates are changing almost daily, different rates within a yield curve for the next two decades are of special relevance to study the viability of a project. The Euro area yield curve that has been considered for this research takes into account both, the Euribor rates based on interbank loans of the Euro area and longer maturities of interest rates of the most relevant European bonds, particularly the German bond. Projections of the yield curve are from September 27th, 2022 and are based on Bloomberg analyses. Furthermore, and since cash inflows may be monetary benefits or savings, for all the financial indicators calculated in this research the gross income and revenues are based on savings resulting from the use of the alternative studied against that of the traditional option (Zadeh *et al*., 2013; Abdelhay & Abunaser, 2021).

Before calculating the traditional indicators, and in order to complete a detailed LCCA, it is also crucial to develop an initial cost structure based on the start-up costs that are needed for the constructed wetland (Bassi *et al*., 2022; Bolinches *et al*., 2022). For this survey construction and operational costs have been evaluated based on primary data. Data collection has been done in the last quarter of 2022 by contacting local, national and international companies which provided internal data, local, national and international authorities which provided public reporting and data and stakeholders. Data from the different sources were crossed and validated before being used in this research. The initial investment has been calculated based on the materials needed for the construction of the wetland that have been provided by local supply companies, but double-checked with international companies in order to see that data, and therefore results, used for this research can be easily extrapolated to other areas where water scarcity is an issue.

The following assumptions have been made:

– The project lifetime has been set at 20 years as in previous VFCW assessments (Abdelhay & Abunaser, 2021; Lakho *et al*., 2022).
– Discount rates are different each year and are based on the Euro area yield curve.
– Costs derived from constructing and installing a VFCW system at a restaurant of medium level with local knowledge and resources were independently investigated and collected through a market survey.

Economic indicators

NPV

To carry out an economic analysis that displays the financial viability of using a VFCW, the NPV was adopted. The NPV is the difference between cash inflows and outflows during a certain period by taking into consideration a discount rate. Its result may be positive or negative, and while a positive magnitude reflects net profit and therefore the desirability of the project, a negative figure shows the lack of economic profitability. This means that the higher the NPV, the greater its profitability.

The NPV has been calculated according to the following equation:

$$\mathrm{NPV} = \sum_{n=0}^{N} \left(\frac{R_n - C_n}{(1+d)^n} \right) \tag{1}$$

where:

d	Discount rate (%)
R	Revenues or Savings (EUR)
C	Costs (EUR)
n	Number of years (from 0 to n)

IRR

The IRR studies project viability and is a representation of the discount rate that equalizes the NPV to zero which means that if the rate resulting from the calculations is higher than the interest rate considered for the investment of the project, it can be implemented due to its profitability. In order to accept an investment based on its IRR, it has to be higher than the average interest rate during the lifespan of the project.

$$IRR = \sum_{k=0}^{n} (R_k) \left(\frac{P}{F}, i'\%, k\right) = \sum_{k=0}^{n} (E_k) \left(\frac{P}{F}, i'\%, k\right) \tag{2}$$

where:

R_k	Net Revenues or Savings for the *k*th year
E_k	Net Expenditures
N	Project lifespan
$i'\%$	Discount rate

DPP

The DPP is used as an indicator that shows the return time of the investment. Through taking into account the time value of money cash flows or savings, it mostly shows the liquidity of a project (Sullivan *et al.*, 2015). When the DPP is less than the project life span it shows the economic feasibility and the project acceptance (Ghafourian *et al.*, 2022). The DPP has been calculated as follows:

$$DPP = \sum_{k=0}^{n} (R_k - E_k) \left(\frac{P}{F}, i'\%, k\right) - I \geq 0 \tag{3}$$

where:

R_k	Net Revenues or Savings for the *k*th year
E_k	Net Expenditures
N	Project lifespan
$i'\%$	Discount rate

BCR

The BCR is used in CBA with the objective of summarizing the overall relationship between costs and benefits of a proposed investment. When the BCR is >1 the project shows suitability and desirability (Bhandari *et al.*, 2021).

$$BCR = \frac{TV}{TC} \tag{4}$$

where:
TV Total Value of the production (in terms of savings)
TC Total Cost of the production

VFCW Profit

Including costs to the economic analysis enhances the comparison of the benefits or savings against the expenses derived from the initial investment and its subsequent operation and shows if profits outweigh expenses and whether the project may provide a net benefit (Bolinches *et al.*, 2022). Production costs in reference to the expenses involved in the useful life of the VFCW and may be fixed or variable.

$$\text{VFCW Profit} = \text{TP} - \text{TC} \tag{5}$$

where:
TP Total Production
TC Total Costs (Fixed and Variable)

Monetary evaluation of the treatment costs

Environmental consequences of using traditional alternatives for water supply and sewerage have a negative impact that too often goes unnoticed due to the difficulties in measuring them. In this context, and in order to carry out comprehensive research that includes not only traditional methodology evaluating the use of new alternatives of water supply from a financial perspective, but also new ways of assessing the use of DWTS, the removal cost of each indicator that was previously assessed in a LCA has been calculated. These costs were calculated based on data published in the "Environmental prices Handbook-EU28" and the environmental prices calculated in this research indicate the social marginal value of preventing emissions from an average source in Europe (De Bruyn *et al*. 2018). Furthermore, these prices are specially modelled for the impact indicators obtained through ReCiPe midpoint method 2016 (hierarchal approach) during Life Cycle Assessment (Goedkoop *et al*., 2009). Meanwhile, the same mid-point method was used during LCA of the decentralized water treatment systems and their conventional alternatives in a previous study that was carried out (Lakho *et al*., 2022). On top of this, and due to the high inflation rates that have been seen over the past months, a price update has been conducted in order to adjust the database used to the current reality and enhance and adapt results based on deviations in the annual growth rate of the GDP (Gross Domestic Product) implicit deflator (Agiakloglou & Gkouvakis, 2022). To measure price changes, the Euro zone Consumer Price Index (CPI) has been used, as it is an expenditure-weighted index that includes the most relevant good and services that compose the consumer market basket, and it is also the most widely used index for calculating price variations (Krimpas *et al*., 2021; Karaduić & Đalović, 2021). Finally, CPI is an indicator of great importance because it is the way to measure the inflation that better reflects how changes in prices affect consumers (Malik *et al*., 2022; Mohammed, 2022).

Results

Initial investment and fixed costs

For the construction of the wetland, as well as the wetland structure itself, a membrane-based potable water production system was also needed. The initial investment considered for all of the calculations throughout this research is the sum of both constructions. Since the main goal of the construction of the VFCW is to treat the wastewater produced from running the restaurant, the costs considered are those planned for an operation of five days per week, fifty-two weeks per year and a period of twenty years. This means that the initial investment figures have been calculated for a VFCW that is going to be capable of treating 20,800m^3 of wastewater during its useful life. Table 1 shows TC of the VFCW and the membrane-based potable system. TP is based on the savings derived from choosing VFCW against the traditional alternative. TC are made up of those costs derived from materials, labour, transportation and control tasks. Labour costs have been measured taking into account the amount of working hours needed for the construction, and the collective labour agreement for construction workers in Belgium. Transportation costs have been calculated for an average distance of 250km. Since its contribution to the total initial cost is <1%, costs associated to transport are not representative enough to be evaluated in different scenarios based on different locations of the VFCW since results might only differ slightly. On the other hand, control tasks refer to location visits, sample collections, site follow-ups or control meetings. All the data, including transportation, labour and control tasks has gone through a validation phase where a minimum of two different specialized companies per entry verified its accuracy. Furthermore, a company entrusted with the construction and installation of CW has double-checked data shown in this research. Fixed costs have been calculated based on the needs of materials that membranes and their useful life. Due to high fluctuations in the energy prices in the year where this research was carried out, the cost of the energy used for the CW operation has been calculated based on an interval of prices during the last 12 months and an average price per kilowatt was selected. Although the energy cost may be considered a variable cost, since the difference between the most expensive scenario of the price interval and the cheapest one has a weight for the whole lifespan of the project of >0.5% of the total investment, it has been included among other fixed costs.

Economic indicators

Table 2 shows the traditional financial indicators that have been used to evaluate the investment discussed in this paper. Total savings of the 20 year-period have been split into average yearly income to calculate gross income and each fixed cost has been recorded in its corresponding year thus having yearly variations in the annual flows. The NPV of the total investment is 8,439.66EUR which is not only acceptable for being positive but also highly desirable. Since interest rates depend on the yield curve and in order to have a single value that can be compared with the IRR, an average interest rate for all the periods has been calculated. This mean rate, 2.59% is higher than the IRR of the project which is 3.79% thus indicating its acceptance and desirability. Likewise, the DPP reflects the economic profitability of the project in terms of liquidity since the repayment of the investment occurs when it still has almost three years of useful life. In the same vein, the BCR is 1.42, and for being higher than the unit this ratio is also shows similar results to the other the financial indicators, proving the economic viability of the investment. Finally, the gross income of the project is 26,419.97EUR which is almost 42% of the total investment and also reflects the project profitability and the interest in the investment for being worthwhile.

Cleaning cost

Results show how for all of the impact categories evaluated for both scenarios, the conventional water supply and sewerage system and the VFCW, results show how removal cost for the first that are displayed in Table 3 are always more expensive than those of the second. Although there are some variables where costs of cleaning for both scenarios are not overly high and the difference between both alternatives studied is not hugely relevant in terms of costs, the total difference between the two potential investments is 1,984,335EUR. Tables 3 and 4 show the monetary evaluation of the removal cost of CWS and VFCW respectively. Costs displayed in these tables, apart from being high by itself, can be seen as even higher if the fact that calculations are based on a 63,021.03EUR project investment is taken into account. Furthermore, it is of great importance to highlight the fact that 80% of the variables, and therefore 4 out of 5, have a removal cost for the traditional water supply and sewerage system that is at least double that of the cleaning cost of the VFCW and in fact, almost 50% of them are three times as much.

In order to represent within the same graph, all the fifteen values for which cleaning costs have been calculated, and with the objective of reducing disparities in costs depending on each variable, data shown in Tables 5 and 6 has been displayed in Figure 2 through Napierian or natural logarithm. Calculating Napierian logarithm of cleaning costs values enhances the presentation of the results derived from calculations, showing them in a clear and visual way while reflecting the relevance and the superiority of the VCTW against its traditional competitor.

Figure 2 shows how the cleaning costs of a decentralized wastewater treatment system against conventional water supply and sewerage deliver better results for all the fifteen variables considered. This situation apart from being more desirable from the environmental perspective, is also more cost-effective in terms of economic profitability since costs calculated here go too often unnoticed and end up being absorbed by humans, animals and the environment through negative externalities.

Discussion

The implementation of DWTS based on VFCWs coupled with a membrane-based drinking water unit as an alternative source of water as opposed to the conventional sewage treatment and water supply has been verified in this research as a cost-effective and environmentally responsible alternative. Its key value has been evidenced not only from the financial perspective of its investment, which has been strongly recommended by all the traditional indicators and ratios calculated, but also from the economic implications that its implementation has regarding the environment. Traditional indicators considered for the LCCA analysis have shown the profitability of the project, while cleaning costs have stated the importance of fostering this alternative to reduce the economic consequences of the environmental impact of the traditional water supply and sewerage system. Calculations where most negative effects were derived from the use of both the traditional alternative and VFCW, and their consequences, have been monetarily evaluated and have demonstrated the importance of implementing the second in order to promote the reduction of the negative externalities and boost the positives. Moreover, developing the construction of VFCWs to treat wastewater has proved to have important benefits in terms of environmental, human, and animal protection that are often unnoticed due to the difficulties in measuring them from an economic and financial approach that allows valuation and comparison.

Results conclude that VFCW apart of being a cost-effective and profitable alternative for an investor, it has also very valuable benefits for the society in general because of its meaningful and positive externalities, the high removal cost of the environmental pollutants of the traditional water supply and sewage system and the contribution to meet SDGs. Furthermore, 4/5 environmental impacts derived from the use of traditional alternative pollute more than twice as much as the VFCW does. Lastly, the treatment costs difference between the VFCW against the traditional alternative is 1,984,335 EUR, being the first far more desirable from an economic and environmental point of view. Results show how for all of the impact categories evaluated for both scenarios (the conventional water supply and sewerage system compared to the VFCW) the treatment cost for the traditional alternative that are displayed in Table 5 are always more expensive than those for the VFCW.

Conclusions

The scope of this research is of great importance if the value of water worldwide is taken into account. VFCWs have been verified in this study as a viable alternative that may enhance water supply in those areas where the traditional systems are either inexistent or unprofitable. Furthermore, all the traditional financial indicators used here to analyze the viability of the investment have stated the desirability of the project from an economic point of view and, moreover, the evaluation of the treatment costs of VFCW against the traditional alternative bolster the importance of fostering the construction of VFCW to help both the environment and the society. In this context, VFCWs are especially useful in rural areas that are not connected to public sewerage systems because of long distances or a small population. For these reasons, VFCWs may also help with combating rural exodus since the construction of traditional water supply and sewerage systems is often far too expensive and unprofitable for the low number of people who would benefit from their construction. In these situations, building VFCWs would benefit all the stakeholders; the government by saving money if compared with the traditional alternative, citizens by having a way of treating wastewater is an environmentally friendly manner, and all the society as a whole by developing sustainable communities and promoting rural development that are also a fundamental part of SDGs.

Last, but not least, results derived from this research justify the construction of VFCWs to treat wastewater as being cost-effective for all, the investor, the environment, and society in general. The use of VFCWs for treating wastewater also makes an indirect contribution to the economy since as well as enhancing economic development through standalone businesses like restaurants, it also promotes the protection of water bodies, their availability, and regeneration. This in turn enhances its use in other contexts and economic sectors where water resources are of vital importance, and its implementation would uplift the achievement of SDGs due to the critical role water supply has directly and indirectly on their fulfilment.

Some limitations of this research might be linked to the availability of supplies needed for the construction of the VFCW that can be hard to find in some geographical regions, especially in underdeveloped countries where rural areas are of great importance and water supply a key issue affecting millions of people. On the other hand, the "yuck factor" also deserves special attention, since it may slow down or even stop the reuse of treated wastewater based on wrong extended beliefs and perceptions that consider this alternative water resource as negative or even harmful. Another limitation that might limit the scope of this research is linked with the relatively high initial investment. This, together with the current high interest rate scenario may be potential barriers for the successful implementation of VFCWs. In this sense, public authorities could really foster their adoption through public grants or loans thus reducing or minimizing the initial economic effort. Furthermore, public, and international institutions could enhance the construction of VFCW by subsidizing part of the initial investment or through tax incentives for those people investing in this green technology that foster sustainable development within the framework of circular economy. Finally, another limitation of this research may be connected with the traditional financial indicators used in the methodology as qualitative variables and risk factors are not assessed.

Against this background, and in order to solve the problem of the potential disadvantage that the unavailability of supplies may cause, future research should focus on looking for easy-to-supply alternatives and materials with which to construct the VFCW itself and the Membrane-based potable water production system. Apart from that, and since this research is based on a previous LCA, where an analysis of a mobile CW to treat grey water at music festivals against the traditional bottled water was also carried out, future research could include its LCCA and the monetary evaluation of its treatment costs.

References

Abdelhay, A., & Abunaser, S. G. (2021). Modeling and economic analysis of grey-water treatment in rural areas in Jordan using a novel vertical-flow constructed wetland. *Environmental Management*, *67*(3), 477–488. doi: 10.1007/s00267-020-0134 9-7.

Abdulfatah, H. K., Stanley, O. I., Nzerem, P., & Jakada, K. (2019). Defining the optimal development strategy to maximize recovery and production rate from an integrated offshore water-flood project. Paper presented at the SPE Nigeria Annual International Conference and Exhibition, Lagos, Nigeria, August 2019. doi: 10.2118/198843-MS.

Agiakloglou, C., & Gkouvakis, M. (2022). Policy implications and welfare analysis under the possibility of default for the Euro zone area. *Journal of Economic Asymmetries*, *25*, e00246. doi: 10.1016/j.jeca.2022.e00246.

AL-agele, H. A., Nackley, L., & Higgins, C. W. (2021). A pathway for sustainable agriculture. *Sustainability*, *13*(8), 4328. doi: 10.3390/su13084328.

Arellano-Gonzalez, J., Aghakouchak, A., Levy, M. C., Qin, Y., Burney, J., Davis, S. J., & Moore, F. C. (2021). The adaptive benefits of agricultural water markets in California. *Environmental Research Letters*, *16*(4), 044036. doi: 10.1088/1748-9326/ abde5b.

Ashu, A. B., & Lee, S. Il. (2021). The effects of climate change on the reuse of agricultural drainage water in irrigation. *KSCE Journal of Civil Engineering*, *25*(3), 1116–1129. doi: 10.1007/s12205-021-0004-2.

Baggio, G., Qadir, M., & Smakhtin, V. (2021). Freshwater availability status across countries for human and ecosystem needs. *Science of the Total Environment*, *792*, 148230. doi: 10.1016/j.scitotenv.2021.148230.

Balk, D., Leyk, S., Montgomery, M. R., & Engin, H. (2021). Global harmonization of urbanization measures: Proceed with care. *Remote Sensing*, *13*(24), 1–26. doi: 10.3390/rs13244973.

Bassi, N., Kumar, S., Kumar, M. D., Van Ermen, S., & Campling, P. (2022). Promoting wastewater treatment in India: Critical questions of economic viability. *Water and Environment Journal*, *36 (4), 723-736*. doi: 10.1111/wej.12810.

Bhandari, S. N., Schlüter, S., Kuckshinrichs, W., Schlör, H., Adamou, R., & Bhandari, R. (2021). Economic feasibility of agrivoltaic systems in food-energy nexus context: Modelling and a case study in niger. *Agronomy*, *11*(10), 1906. doi: 10.3390/agronomy11101906.

Bolinches, A., Blanco-Gutiérrez, I., Zubelzu, S., Esteve, P., & Gómez-Ramos, A. (2022). A method for the prioritization of water reuse projects in agriculture irrigation. *Agricultural Water Management*, *263, 107435*. doi: 10.1016/j.agwat.2021. 107435.

Brennan, M., Rondón-Sulbarán, J., Sabogal-Paz, L. P., Fernandez-Ibañez, P., & Galdos-Balzategui, A. (2021). Conceptualising global water challenges: A trans-disciplinary approach for understanding different discourses in sustainable development. *Journal of Environmental Management*, *298*, *113361*. doi: 10.1016/j.jenvman.2021.113361.

Bunn, S. E. (2016). Grand challenge for the future of freshwater ecosystems. *Frontiers in Environmental Science*, *4*, 1–4. doi: 10.3389/fenvs.2016.00021.

Cao, Z., Zhou, L., Gao, Z., Huang, Z., Jiao, X., Zhang, Z., Ma, K., Di, Z., & Bai, Y. (2021). Comprehensive benefits assessment of using recycled concrete aggregates as the substrate in constructed wetland polishing effluent from wastewater treatment plant. *Journal of Cleaner Production*, *288*, 125551. doi: 10.1016/j.jclepro.2020.125551.

Castellar, J. A. C., Torrens, A., Buttiglieri, G., Monclús, H., Arias, C. A., Carvalho, P. N., Galvao, A., & Comas, J. (2022). Nature-based solutions coupled with advanced technologies: An opportunity for decentralized water reuse in cities. *Journal of Cleaner Production*, *340*, 130660. doi: 10.1016/j.jclepro.2022.130660.

Corbella, C., Puigagut, J., & Garfí, M. (2017). Life cycle assessment of constructed wetland systems for wastewater treatment coupled with microbial fuel cells. *Science of the Total Environment*, *584–585*, 355–362. doi: 10.1016/j.scitotenv.2016.12.186.

Cui, X., Wang, J., Wang, X., Khan, M. B., Lu, M., Khan, K. Y., Song, Y., He, Z., Yang, X., Yan, B., & Chen, G. (2022). Biochar from constructed wetland biomass waste: A review of its potential and challenges. *Chemosphere*, *287*(P3), 132259. doi: 10.1016/j.chemosphere.2021.132259.

De Bruyn, S., Bijleveld, M., de Graaff, L., Schep, E., Schroten, A., Vergeer, R., & Ahdour, S. (2018). Environmental prices handbook. Committed to the Environment Delft, 18.7N54.12, 176. Retrieved from https://cedelft.eu/publications/environmental-prices-handbook-eu28-version/ (20.10.2022).

Declercq, R., Loubier, S., Condom, N., & Molle, B. (2020). Socio-economic interest of treated wastewater reuse in agricultural irrigation and indirect potable water reuse: Clermont-Ferrand and Cannes case studies' cost–benefit analysis. *Irrigation and Drainage*, *69*(S1), 194–208. doi: 10.1002/ird.2205.

Deng, S., Chen, J., & Chang, J. (2021). Application of biochar as an innovative substrate in constructed wetlands/biofilters for wastewater treatment: Performance and ecological benefits. *Journal of Cleaner Production*, *293*, 126156. doi: 10.1016/j.jclepro.2021.126156.

Dev, A., Dilly, T. C., Bakhshipour, A. E., Dittmer, U., & Bhallamudi, S. M. (2021). Optimal implementation of wastewater reuse in existing sewerage systems to improve resilience and sustainability in water supply systems. *Water*, *13*(15), 2004. doi: 10.3390/w13152004.

Di Vaio, A., Trujillo, L., D'Amore, G., & Palladino, R. (2021). Water governance models for meeting sustainable development goals: A structured literature review. *Utilities Policy*, *72*, 101255. doi: 10.1016/j.jup.2021.101255.

Diao, K. (2021). Towards resilient water supply in centralized control and decentralized execution mode. *Aqua Water Infrastructure, Ecosystems and Society*, *70*(4), 449–466. doi: 10.2166/aqua.2021.162.

Diaz-Elsayed, N., Rezaei, N., Ndiaye, A., & Zhang, Q. (2020). Trends in the environmental and economic sustainability of wastewater-based resource recovery: A review. *Journal of Cleaner Production*, *265*, 121598. doi: 10.1016/j.jclepro.2020.121598.

Dumax, N., & Rozan, A. (2021). Valuation of the environmental benefits induced by a constructed wetland. *Wetlands Ecology and Management*, *29*(6), 809–822. doi: 10.1007/s11273-021-09811-x.

Estelrich, M., Vosse, J., Comas, J., Atanasova, N., Costa, J. C., Gattringer, H., & Buttiglieri, G. (2021). Feasibility of vertical ecosystem for sustainable water treatment and reuse in touristic resorts. *Journal of Environmental Management*, *294*, 112968. doi: 10.1016/j.jenvman.2021.112968.

Estévez, S., González-García, S., Feijoo, G., & Moreira, M. T. (2022). How decentralized treatment can contribute to the symbiosis between environmental protection and resource recovery. *Science of the Total Environment*, *812*, 151485. doi: 10.1016/j.scitotenv.2021.151485.

Freeman, A. I., Widdowson, S., Murphy, C., & Cooper, D. J. (2019). Economic assessment of aerated constructed treatment wetlands using whole life costing. *Water Science and Technology*, *80*(1), 75–85. doi: 10.2166/wst.2019.246.

Galvis, A., Jaramillo, M. F., van der Steen, P., & Gijzen, H. J. (2018). Financial aspects of reclaimed wastewater irrigation in three sugarcane production areas in the Upper Cauca river Basin, Colombia. *Agricultural Water Management*, *209*, 102–110. doi: 10.1016/j.agwat.2018.07.019.

Gattringer, H., Claret, A., Radtke, M., Kisser, J., Zraunig, A., Odriguez-Roda, I., & Buttiglieri, G. (2016). Novel vertical ecosystem for sustainable water treatment and reuse in tourist resorts. *International Journal of Sustainable Development and Planning*, *11*(3), 263–274. doi: 10.2495/SDP-V11-N3-263-274.

Ghafourian, M., Nika, C. E., Mousavi, A., Mino, E., Al-Salehi, M., & Katsou, E. (2022). Economic impact assessment indicators of circular economy in a decentralised circular water system — case of eco-touristic facility. *Science of the Total Environment*, *822*, 153602. doi: 10.1016/j.scitotenv.2022.153602.

Goedkoop, M., Heijungs, R., Huijbregts, M., Schryver, A. De, Struijs, J., & Zelm, R. Van. (2009). ReCiPe 2008. Potentials, May 2014, 1–44. Retrieved from http://www.pre-sustainability.com/download/misc/ReCiPe_main_report_final_27-02-2009_web.pdf (20.10.2022).

Gukelberger, E., Gabriele, B., Hoinkis, J., & Figoli, A. (2018). MBR and integration with renewable energy toward suitable autonomous wastewater treatment. In *Current trends and future developments on (bio-) membranes: Renewable energy integrated with membrane operations*. Elsevier. doi: 10.1016/B978-0-12-813545-7.00014-3.

Hasik, V., Anderson, N. E., Collinge, W. O., Thiel, C. L., Khanna, V., Wirick, J., Piacentini, R., Landis, A. E., & Bilec, M. M. (2017). Evaluating the life cycle environmental benefits and trade-offs of water reuse systems for net-zero buildings. *Environmental Science and Technology*, *51*(3), 1110–1119. doi: 10.1021/acs.est.6b03879.

Hejduková, P., & Kureková, L. (2020). Water scarcity: Regional analyses in the Czech Republic from 2014 to 2018. *Oeconomia Copernicana*, *11*(1), 161–181. doi: 10.24136/oc.2020.007.

Hristov, J., Barreiro-Hurle, J., Salputra, G., Blanco, M., & Witzke, P. (2021). Reuse of treated water in European agriculture: Potential to address water scarcity under climate change. *Agricultural Water Management*, *251*, 106872. doi: 10.1016/j.agwat.2021.106872.

Jahne, M. A., Brinkman, N. E., Keely, S. P., Zimmerman, B. D., Wheaton, E. A., & Garland, J. L. (2020). Droplet digital PCR quantification of norovirus and adenovirus in decentralized wastewater and graywater collections: Implications for onsite reuse. *Water Research*, *169*, 115213. doi: 10.1016/j.watres.2019.115213.

Karaduić, V., & Đalović, N.. (2021). Profitability determinants of big european banks. *Journal of Central Banking Theory and Practice*, *10*(2), 39–56. doi: 10.2478/jcbtp-2021-0013.

Kataki, S., Chatterjee, S., Vairale, M. G., Sharma, S., Dwivedi, S. K., & Gupta, D. K. (2021). Constructed wetland, an eco-technology for wastewater treatment: A review on various aspects of microbial fuel cell integration, low temperature strategies and life cycle impact of the technology. *Renewable and Sustainable Energy Reviews*, *148*, 111261. doi: 10.1016/j.rser.2021.111261.

Khalkhali, M., Dilkina, B., & Mo, W. (2021). The role of climate change and decentralization in urban water services: A dynamic energy-water nexus analysis. *Water Research*, *207*, 117830. doi: 10.1016/j.watres.2021.117830.

Krimpas, N. A., Salamaliki, P. K., & Venetis, I. A. (2021). Factor decomposition of disaggregate inflation: The case of Greece. *International Journal of Computational Economics and Econometrics*, *11*(1), 84–104. doi: 10.1504/IJCEE.2021.111713.

Kyle, P., Johnson, N., Davies, E., Bijl, D. L., Mouratiadou, I., Bevione, M., Drouet, L., Fujimori, S., Liu, Y., & Hejazi, M. (2016). Setting the system boundaries of "energy for water" for integrated modeling. *Environmental Science and Technology*, *50*(17), 8930–8931. doi: 10.1021/acs.est.6b01066.

Laitinen, J., Moliis, K., & Surakka, M. (2017). Resource efficient wastewater treatment in a developing area—climate change impacts and economic feasibility. *Ecological Engineering*, *103*, 217–225. doi: 10.1016/j.ecoleng.2017.04.017.

Lakho, F. H., Qureshi, A., Igodt, W., Le, H. Q., Depuydt, V., Rousseau, D. P. L., & Van Hulle, S. W. H. (2022). Life cycle assessment of two decentralized water treatment systems combining a constructed wetland and a membrane based drinking water production system. *Resources, Conservation and Recycling*, *178*, 106104. doi: 10.1016/j.resconrec.2021.106104.

Lavrnić, S., Zapater-Pereyra, M., & Mancini, M. L. (2017). Water scarcity and wastewater reuse standards in Southern Europe: Focus on agriculture. *Water, Air, and Soil Pollution*, *228*(7), 251. doi: 10.1007/s11270-017-3425-2.

Licciardello, F., Milani, M., Consoli, S., Pappalardo, N., Barbagallo, S., & Cirelli, G. (2018). Wastewater tertiary treatment options to match reuse standards in agriculture. *Agricultural Water Management*, *210*, 232–242. doi: 10.1016/j.agwat.2018.08.001.

Liu, D., Zou, C., & Xu, M. (2019). Environmental, ecological, and economic benefits of biofuel production using a constructed wetland: A case study in China. *International Journal of Environmental Research and Public Health*, *16*(5), 827. doi: 10.3390/ijerph16050827.

Liu, Y., Sim, A., & Mauter, M. S. (2021). Energy-optimal siting of decentralized water recycling systems. *Environmental Science and Technology*, *55*(22), 15343–15350. doi: 10.1021/acs.est.1c04708.

Loarte-Flores, F., Vasquez-Olivera, Y., Mamani-Macedo, N., Raymundo-Ibañez, C., & Dominguez, F. (2020). Comprehensive strategic risk management system to reduce evaluation times in small-scale mining projects. *Advances in Intelligent Systems and Computing*, *1152 AISC*, 603–609. doi: 10.1007/978-3-030-44267-5_91.

López-Serrano, M. J., Velasco-Muñoz, J. F., Aznar-Sánchez, J. A., & Román-Sánchez, I. M. (2021). Financial evaluation of the use of reclaimed water in agriculture in Southeastern Spain, a mediterranean region. *Agronomy*, *11*(11), 2218. doi: 10.3390/agronomy11112218.

Lourenço, N., & Nunes, L. M. (2021). Life-cycle assessment of decentralized solutions for wastewater treatment in small communities. *Water Science and Technology*, *84*(8), 1954–1968. doi: 10.2166/wst.2021.379.

Lutterbeck, C. A., Kist, L. T., Lopez, D. R., Zerwes, F. V., & Machado, E. L. (2017). Life cycle assessment of integrated wastewater treatment systems with constructed wetlands in rural areas. *Journal of Cleaner Production*, *148*, 527–536. doi: 10.1016/j.jclepro.2017.02.024.

Makropoulos, C., Rozos, E., Tsoukalas, I., Plevri, A., Karakatsanis, G., Karagiannidis, L., Makri, E., Lioumis, C., Noutsopoulos, C., Mamais, D., Rippis, C., & Lytras, E. (2018). Sewer-mining: A water reuse option supporting circular economy, public service provision and entrepreneurship. *Journal of Environmental Management*, *216*, 285–298. doi: 10.1016/j.jenvman.2017.07.026.

Malik, M. F., Awan, M. S., & Malik, W. S. (2022). Determination of inflationary behavior: A comparative analysis. *Cogent Economics and Finance*, *10*(1), 2019360. doi: 10.1080/23322039.2021.2019360.

Maniam, G., Zakaria, N. A., Leo, C. P., Vassilev, V., Blay, K. B., Behzadian, K., & Poh, P. E. (2022). An assessment of technological development and applications of decentralized water reuse: A critical review and conceptual framework. *Wiley Interdisciplinary Reviews: Water*, *9*(3), 1–31. doi: 10.1002/wat2.1588.

Maryati, S., Firman, T., & Humaira, A. N. S. (2022). A sustainability assessment of decentralized water supply systems in Bandung City, Indonesia. *Utilities Policy*, *76*, 101373. doi: 10.1016/j.jup.2022.101373.

Melián-Navarro, A., & Ruiz-Canales, A. (2020). Evaluation in carbon dioxide equivalent and chg emissions for water and energy management in water users associations. A case study in the southeast of spain. *Water*, *12*(12), 3536. doi: 10.3390/w12123536.

Mohammed, R. (2022). The impact of crude oil price on food prices in Iraq. *OPEC Energy Review*, *46*(1), 106–122. doi: 10.1111/opec.12225.

Nuamah, L. A., Li, Y., Pu, Y., Nwankwegu, A. S., Haikuo, Z., Norgbey, E., Banahene, P., & Bofah-Buoh, R. (2020). Constructed wetlands, status, progress, and challenges. The need for critical operational reassessment for a cleaner productive ecosystem. *Journal of Cleaner Production*, *269*, 122340. doi: 10.1016/j.jclepro.2020.122340.

Omole, D. O., Jim-George, T., & Akpan, V. E. (2019). Economic analysis of wastewater reuse in Covenant University. *Journal of Physics: Conference Series*, *1299*(1), 012125. doi: 10.1088/1742-6596/1299/1/012125.

Otter, P., Sattler, W., Grischek, T., Jaskolski, M., Mey, E., Ulmer, N., Grossmann, P., Matthias, F., Malakar, P., Goldmaier, A., Benz, F., & Ndumwa, C. (2020). Economic evaluation of water supply systems operated with solar-driven electrochlorination in rural regions in Nepal, Egypt and Tanzania. *Water Research*, *187*, 116384. doi: 10.1016/j.watres.2020.116384.

Pahl-Wostl, C. (2019). Governance of the water-energy-food security nexus: A multi-level coordination challenge. *Environmental Science and Policy*, *92*, 356–367. doi: 10.1016/j.envsci.2017.07.017.

Pahunang, R. R., Buonerba, A., Senatore, V., Oliva, G., Ouda, M., Zarra, T., Muñoz, R., Puig, S., Ballesteros, F. C., Li, C. W., Hasan, S. W., Belgiorno, V., & Naddeo, V. (2021). Advances in technological control of greenhouse gas emissions from wastewater in the context of circular economy. *Science of the Total Environment*, *792*, 148479. doi: 10.1016/j.scitotenv.2021.148479.

Peñacoba-Antona, L., Senán-Salinas, J., Aguirre-Sierra, A., Letón, P., Salas, J. J., García-Calvo, E., & Esteve-Núñez, A. (2021). Assessing METland® design and performance through LCA: Techno-environmental study with multifunctional unit perspective. *Frontiers in Microbiology*, *12*, 1–14. doi: 10.3389/fmicb.2021.652173.

Pickering, A. J., Crider, Y., Amin, N., Bauza, V., Unicomb, L., Davis, J., & Luby, S. P. (2015). Differences in field effectiveness and adoption between a novel automated chlorination system and household manual chlorination of drinking water in Dhaka, Bangladesh: A randomized controlled trial. *PLoS ONE*, *10*(3), 1–16. doi: 10.1371/journal.pone.0118397.

Ponce-Robles, L., Masdemont-Hernández, B., Munuera-Pérez T., Pagán-Muñoez, A., Lara-Guillén, A. J., García-García, A. J., Pedrero-Salcedo, F., Nortes-Tortorsa, P. A., Alarcón-Cabañero, J. J. (2020). WWTP effluent quality improvement for agricultural reuse using an autonomous prototype. *Water, 12(8), 2240.* doi: 10.3390/w12082240.

Resende, J. D., Nolasco, M. A., & Pacca, S. A. (2019). Life cycle assessment and costing of wastewater treatment systems coupled to constructed wetlands. *Resources, Conservation and Recycling*, *148*, 170–177. doi: 10.1016/j.resconrec.2019.04.034.

Ricart, S., & Rico-Amorós, A. M. (2021). Constructed wetlands to face water scarcity and water pollution risks: Learning from farmers' perception in Alicante, Spain. *Water*, *13*(17), 2431. doi: 10.3390/w13172431.

Rodríguez de Sá Silva, A. C.., Bimbato, A. M., Balestieri, J. A. P., & Vilanova, M. R. N. (2022). Exploring environmental, economic and social aspects of rainwater harvesting systems: A review. *Sustainable Cities and Society*, *76*, 103475. doi: 10.1016/j.scs.2021.103475.

Sakcharoen, T., Ratanatamskul, C., & Chandrachai, A. (2021). Factors affecting technology selection, techno-economic and environmental sustainability assessment of a novel zero-waste system for food waste and wastewater management. *Journal of Cleaner Production*, *314*, 128103. doi: 10.1016/j.jclepro.2021.128103.

Sánchez Pérez, J. A., Arzate, S., Soriano-Molina, P., García Sánchez, J. L., Casas López, J. L., & Plaza-Bolaños, P. (2020). Neutral or acidic pH for the removal of contaminants of emerging concern in wastewater by solar photo-Fenton? A techno-economic assessment of continuous raceway pond reactors. *Science of the Total Environment*, *736*, 139681. doi: 10.1016/j.scitotenv.2020.139681.

Tociu, C., Ciobotaru, I. E., Maria, C., Déak, G., Ivanov, A. A., Marcu, E., Marinescu, F., Savin, I., & Noor, N. M. (2019). Exhaustive approach to livestock wastewater treatment in irrigation purposes for a better acceptability by the public. *AIP Conference Proceedings*, *2129*, 020066. doi: 10.1063/1.5118074.

Truchado, P., Gil, M. I., López, C., Garre, A., López-Aragón, R. F., Böhme, K., & Allende, A. (2021). New standards at European Union level on water reuse for agricultural irrigation: Are the Spanish wastewater treatment plants ready to produce and distribute reclaimed water within the minimum quality requirements? *International Journal of Food Microbiology*, *356*. 109352. doi: 10.1016/j.ijfoodmicro.2021.109352.

UNESCO (2021). *The United Nations world water development report 2021: Valuing water*. Paris: UNESCO.

UNESCO (2022). *Nations world water development report 2022: Groundwater: Making the invisible visible*. Paris: UNESCO.

Vakilifard, N., Anda, M., A. Bahri, P., & Ho, G. (2018). The role of water-energy nexus in optimising water supply systems – review of techniques and approaches. *Renewable and Sustainable Energy Reviews*, *82*, 1424–1432. doi: 10.1016/j.rser.2017.05.125.

Van de Walle, A., Torfs, E., Gaublomme, D., & Rabaey, K. (2022). In silico assessment of household level closed water cycles: Towards extreme decentralization. *Environmental Science and Ecotechnology*, *10*, 100148. doi: 10.1016/j.ese.2022.100148.

Vymazal, J., Zhao, Y., & Mander, Ü. (2021). Recent research challenges in constructed wetlands for wastewater treatment: A review. *Ecological Engineering*, *169*(June), 106318. doi: 10.1016/j.ecoleng.2021.106318.

Wang, M., Mohanty, S. K., & Mahendra, S. (2019). Nanomaterial-supported enzymes for water purification and monitoring in point-of-use water supply systems. *Accounts of Chemical Research*, *52*(4), 876–885. doi: 10.1021/acs.accounts.8b00613.

Wang, X., Müller, C., Elliot, J., Mueller, N. D., Ciais, P., Jägermeyr, J., Gerber, J., Dumas, P., Wang, C., Yang, H., Li, L., Deryng, D., Folberth, C., Liu, W., Makowski, D., Olin, S., Pugh, T. A. M., Reddy, A., Schmid, E., Jeong, S., Zhou, F., & Piao, S. (2021). Global irrigation contribution to wheat and maize yield. *Nature Communications*, *12*(1), 1–8. doi: 10.1038/s41467-021-21498-5.

Weerasooriya, R. R., Liyanage, L. P. K., Rathnappriya, R. H. K., Bandara, W. B. M. A. C., Perera, T. A. N. T., Gunarathna, M. H. J. P., & Jayasinghe, G. Y. (2021). Industrial water conservation by water footprint and sustainable development goals: a review. *Environment, Development and Sustainability*, *23*(9), 12661–12709. doi: 10.1007/s10668-020-01184-0.

Welivita, I., Willcock, S., Lewis, A., Bundhoo, D., Brewer, T., Cooper, S., Lynch, K., Mekala, S., Mishra, P. P., Venkatesh, K., Vicario, D. R., & Hutchings, P. (2021). Evidence of similarities in ecosystem service flow across the rural-urban spectrum. *Land*, *10*(4), 1–38. doi: 10.3390/land10040430.

Wu, H., Zhang, J., Ngo, H. H., Guo, W., Hu, Z., Liang, S., Fan, J., & Liu, H. (2015). A review on the sustainability of constructed wetlands for wastewater treatment: Design and operation. *Bioresource Technology*, *175*, 594–601. doi: 10.1016/j.biort ech.2014.10.068.

Yang, H., Chen, J., Yu, L., Li, W., Huang, X., Qin, Q., & Zhu, S. (2022). Performance optimization and microbial community evaluation for domestic wastewater treatment in a constructed wetland-microbial fuel cell. *Environmental Research*, *212*, 113249. doi: 10.1016/j.envres.2022.113249.

Zadeh, S. M., Hunt, D. V. L., Lombardi, D. R., & Rogers, C. D. F. (2013). Shared urban greywater recycling systems: Water resource savings and economic investment. *Sustainability*, *5*(7), 2887–2912. doi: 10.3390/su5072887.

Zagklis, D. P., & Bampos, G. (2022). Tertiary wastewater treatment technologies: A review of technical, economic, and life cycle aspects. *Processes*, *10*(11), 2304. doi: 10.3390/pr10112304.

Zhang, H., Tang, W., Wang, W., Yin, W., Liu, H., Ma, X., Zhou, Y., Lei, P., Wei, D., Zhang, L., Liu, C., & Zha, J. (2021). A review on China's constructed wetlands in recent three decades: Application and practice. *Journal of Environmental Sciences*, 104, 53–68. doi: 10.1016/j.jes.2020.11.032.

Acknowledgments

This work was partially supported by the Research Plan of the University of Almería.

Ministry of Education and Science
Republic of Poland

The journal is co-financed in the years 2022–2024 by the Ministry of Education and Science of the Republic of Poland in the framework of the ministerial programme "Development of Scientific Journals" (RCN) on the basis of contract no. RCN/SN/0129/2021/1concluded on 29 September 2022 and being in force until 28 September 2024.

Annex

Table 1. TC of the VFCW and the membrane-based potable system: Construction and Fixed costs

ITEM		*COST (EUR)*
	INITIAL INVESTMENT OF THE VFCW	
Septic tank (concrete)		2,700
Buffer tank (concrete)		945
Concrete slab		3,600
PE Liner		70
Lava rock		2,970
Rockwool		16,154.88
Pipe Joints		58.18
Silicone product (Pipe)		34.95
Water Valve		34.95
PVC Pipe		119.97
Labour (2p)		13,200
Control tasks		690
Transportation costs		505
	TOTAL	**39,887.93**
	MEMBRANE-BASED POTABLE WATER PRODUCTION SYSTEM	
Pump (0.81KW)		232
Microfiltration membrane (MF. HYDRA brand)		86.64
Activated carbon (brand FA100)		43.32
UF membrane (Polymem. Type UF 35 G S2F)		408.3
RO membrane (DOW FILMTEC BW2530)		164.43
LED-UV lamps (Aquisense. Type Pearl Aqua micro 12C)		59.47
Framework (steel)		2,488.9
Labour for the membrane filtration system construction		15,000
TOTAL		**18,483.06**

Table 1. Continued

ITEM	*COST (EUR)*
	FIXED COSTS 20-YEAR PERIOD (MEMBRANE)
Pump (0.81KW)	464
Microfiltration membrane (MF. HYDRA brand)	259.92
Activated carbon (brand FA100)	173.3
UF membrane (Polymem. Type UF 35 G S2F)	1224.9
RO membrane (DOW FILMTEC BW2530)	493.28
LED-UV lamps (Aquisense. Type Pearl Aqua micro 12C)	118.94
Energy consumption (218.4kWh/year)	36.04
TOTAL	**2270.3**

Table 2. Traditional financial indicators to evaluate an investment

Year	*Gross Income*	*Fixed Costs*	*Annual Flow*	*Interest Rate*	*NPV*	*IRR*	*DPP*
	Initial investment	→	-59,522.67		**8,439.66**	**3.79%**	**17.33**
1	4,472	36.04	4,435.96	3.38%	4,291.01	Average Interest Rate	
2	4,472	36.04	4,435.96	3.08%	4,174.83	2.59% < 3.79%	
3	4,472	36.04	4,435.96	3.00%	4,059.54	***BCR***	
4	4,472	70.69	4,401.31	2.99%	3,912.78	**1.42**	
5	4,472	695.40	3,776.60	2.95%	3,266.12	***Gross Income***	
6	4,472	268.04	4,203.96	2.91%	3,538.86	**26,418.97**	
7	4,472	130.16	4,341.84	2.97%	3,537.52		
8	4,472	36.04	4,435.96	3.01%	3,497.99		
9	4,472	36.04	4,435.96	3.05%	3,384.98		
10	4,472	730.06	3,741.94	3.00%	2,784.36		
11	4,472	36.04	4,435.96	2.91%	3,235.60		
12	4,472	268.04	4,203.96	2.65%	3,071.51		
13	4,472	70.69	4,401.31	2.65%	3,132.68		
14	4,472	95.51	4,376.49	2.63%	3,042.89		

Table 2. Continued

Year	*Gross Income*	*Fixed Costs*	*Annual Flow*	*Interest Rate*	*NPV*	*IRR*	*DPP*
Initial investment		→	-59,522.67		**8,439.66**	**3.79%**	**17.33**
15	4,472	695.40	3,776.60	1.77%	2,902.71		
16	4,472	70.69	4,401.31	1.77%	3,324.03		
17	4,472	36.04	4,435.96	1.78%	3,286.45		
18	4,472	36.04	4,435.96	1.78%	3,228.97		
19	4,472	36.04	4,435.96	1.78%	3,172.50		
20	4,472	36.04	4,435.96	1.78%	3,117.02		

Table 3. Monetary evaluation of the removal cost of a CWS

IMPACT CATEGORY	*UNIT*	*COST*	*CONVENTIONAL WATER SUPPLY AND SEWERAGE*	
			Impacts	**Cost** (EUR)
FINE PARTICULATE MATTER FORMATION	kg $PM_{2.5}$ eq	38.7 EUR.kg^{-1} $PM_{2.5}$ eq	$1.27\times10^{+02}$	**5601.51**
FRESHWATER ECOTOXICITY	kg 1.4-DCB	0.04 EUR.kg^{-1} 1.4-DCB	$3.91\times10^{+03}$	**178.48**
FRESHWATER EUTROPHICATION	kg P eq	1.86 EUR.kg^{-1} P eq	$3.20\times10^{+01}$	**68.00**
GLOBAL WARMING	kg CO_2 eq	0.057 EUR.kg^{-1} CO_2 eq	$9.37\times10^{+04}$	**6096.79**
HUMAN CARCINOGENIC TOXICITY	kg 1.4-DCB	0.153 EUR.kg^{-1} 1.4-DCB	$1.86\times10^{+04}$	**3248.91**
HUMAN NON-CARCINOGENIC TOXICITY	kg 1.4-DCB	0.153 EUR.kg^{-1} 1.4-DCB	$5.44\times10^{+04}$	**9490.80**
IONIZING RADIATION	kBq Co-60 eq	0.00020 EUR.kBq^{-1} Co-60 eq	$5.69\times10^{+03}$	**1.30**
LAND USE	m²a crop eq	0.084 EUR.m^{-2}	$2.49\times10^{+03}$	**238.79**

Table 3. Continued

IMPACT CATEGORY	*UNIT*	*COST*	*CONVENTIONAL WATER SUPPLY AND SEWERAGE*	
			Impacts	**Cost** (EUR)
MARINE ECOTOXICITY	kg 1.4-DCB	0.008 EUR.kg^{-1} 1.4-DCB	$5.28\times10^{+03}$	**48.15**
MARINE EUTROPHICATION	kg N eq	3.11 EUR.kg^{-1} N eq	$2.62\times10^{+00}$	**9.29**
OZONE FORMATION, HUMAN HEALTH	kg NO_X eq	1.1 EUR.kg^{-1} NO_X eq	$2.39\times10^{+02}$	**300.56**
OZONE FORMATION, TERRESTRIAL ECOSYSTEMS	kg NO_X eq	1.1 EUR.kg^{-1} NO_X eq	$2.46\times10^{+02}$	**308.40**
STRATOSPHERIC OZONE DEPLETION	kg CFC11 eq	123 EUR.kg^{-1} CFC-11 eq	3.85×10^{-02}	**5.40**
TERRESTRIAL ACIDIFICATION	kg SO_2 eq	0.764 EUR.kg^{-1} SO_2 eq	$2.80\times10^{+02}$	**244.04**
TERRESTRIAL ECOTOXICITY	kg 1.4-DCB	8.69 EUR.kg -1 1.4-DCB	$2.68\times10^{+05}$	**2,661,252.79**

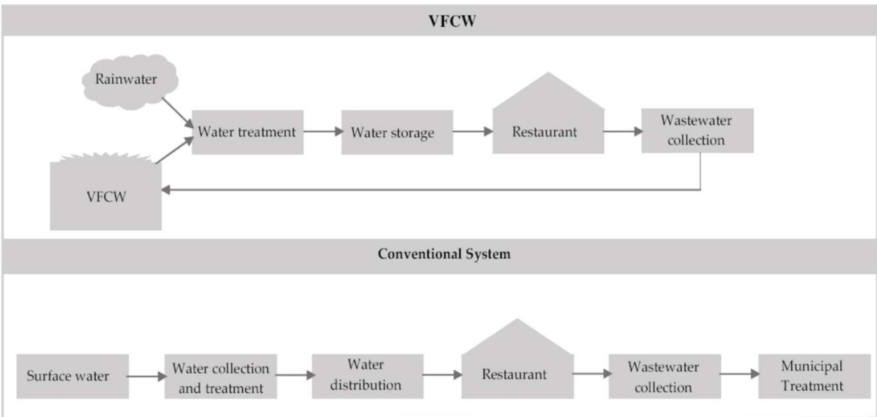
Table 4. Monetary evaluation of the removal cost of a VFCW

IMPACT CATEGORY	*UNIT*	*COST*	*VFCW*	
			Impacts	**Cost** (EUR)
Fine Particulate Matter Formation	kg $PM_{2.5}$ eq	38.7 EUR.kg^{-1} $PM_{2.5}$ eq	$.95\times10^{+01}$	**2185.40**
Freshwater Ecotoxicity	kg 1.4-DCB	0.04 EUR.kg^{-1} 1.4-DCB	$.63\times10^{+03}$	**165.80**
Freshwater Eutrophication	kg P eq	1.86 EUR.kg^{-1} P eq	$.14\times10^{+01}$	**24.27**
Global Warming	kg CO_2 eq	0.057 EUR.kg^{-1} CO_2 eq	$.42\times10^{+04}$	**1577.03**
Human Carcinogenic Toxicity	kg 1.4-DCB	0.153 EUR.kg^{-1} 1.4-DCB	$.33\times10^{+03}$	**929.88**

Table 4. Continued

IMPACT CATEGORY	*UNIT*	*COST*	*VFCW*	
			Impacts	**Cost** (EUR)
Ionizing Radiation	kBq Co-60 eq	0.00020 EUR.kBq^{-1} Co-60 eq	$.26\times10^{+03}$	**0.51**
Land Use	m^{2}a crop eq	0.084 EUR.m^{-2}	$.73\times10^{+02}$	**74.09**
Marine Ecotoxicity	kg 1.4-DCB	0.008 EUR.kg^{-1} 1.4-DCB	$.55\times10^{+03}$	**41.50**
Marine Eutrophication	kg N eq	3.11 EUR.kg^{-1} N eq	$.45\times10^{-01}$	**3.00**
Ozone Formation, Human Health	kg NO_x eq	1.1 EUR.kg^{-1} NO_x eq	$.63\times10^{+01}$	**70.70**
Ozone Formation, Terrestrial Ecosystems	kg NO_x eq	1.1 EUR.kg^{-1} NO_x eq	$.92\times10^{+01}$	**74.31**
Stratospheric Ozone Depletion	kg CFC11 eq	123 EUR.kg^{-1} CFC-11 eq	$.24\times10^{-02}$	**4.55**
Terrestrial Acidification	kg SO_2 eq	0.764 EUR.kg^{-1} SO_2 eq	$.01\times10^{+02}$	**88.03**
Terrestrial Ecotoxicity	kg 1.4-DCB	8.69 EUR.kg-1 1.4-DCB	$.16\times10^{+04}$	**412,381.74**

Figure 1. System boundaries for the scenario studied



Source: Lakho *et al*. (2022).

Figure 2. Napierian logarithm of removal cost