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# A new optimized procedure for circular WasteWater sustainability: Coastal cities supporting agricultural rural communities

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A R T I C L E I N F O

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A B S T R A C T

This proposal introduces a novel methodology that addresses the increasing irrigation demands driven by climate change and urban growth. Traditionally water-scarce areas are now facing severe water deficits, while wastewater volumes from treatment plants, often discharged into the sea, contribute to pollution. The proposed hybrid system strategy innovatively reallocates 33 $hm^3$ of water annually to agricultural communities, employing a zero-discharge approach to prevent marine pollution. Evaluated from energetic, environmental, and social perspectives, this methodology shows a remarkable cost-benefit ratio exceeding 12, showing its feasibility. It features technical indicators for optimizing water distribution and regulatory components, applied effectively to 28,424 ha of farmland. This strategy meets 24.1 % of the irrigation needs in these regions while safeguarding coastal areas from degradation. Crucially, it integrates 11.3 GWh of renewable energy annually, underscoring its sustainability and enhancing its replicability for other water-deficient regions.

## 1. Introduction

Population growth in cities is increasing pressure on the use of services [1]. This increase implies the need to consume high natural resources in terms of food, energy and water. Besides, this consumption requires new efforts to supply the demand by the logistical platforms, increasing the carbon footprint of society. Water is an essential resource in cities and municipalities alike, being necessary for the best management of water resources [2]. Its essentiality is due to the hygiene and sanitation requirements of society, water is a fundamental resource for agricultural production in rural areas [3]. This agricultural production is not only what provides resources for the world's population, but also guarantees an economic environment that fixes the population in the rural world [4].

This implies the need to address green strategies that allow for the reuse of as many resources as possible [5]. Linked to the use of water, encouraging the improvement of the SDG6 assessment, water reuse is a cable fact [6]. In this case, the reuse of water implies not only the introduction of a circular economy in the resource but also the avoidance of pollution of watercourses and seas from reclaimed water from wastewater treatment plants [7]. Direct wastewater discharges contribute significantly to Mediterranean eutrophication [8]. By 2050, phosphorus inputs may rise substantially without intervention, but tertiary treatment and phosphorus management could mitigate this, despite significant costs [9]. Addressing solutions that allow the reuse of water provide greater advantages than those that until now have been considered, which were direct discharge or discharge through marine outfalls [10]. Water management policies must prioritize the development of sustainable alternatives that facilitate wastewater reuse while minimizing the reliance on landfilling practices [11]. Such approaches are critical for mitigating pollution, particularly the presence of biological contaminants and microplastics [12]. The utilization of marine outfalls has proven ineffective in addressing the pervasive issue of microplastics [13], whose accumulation continues to have detrimental effects on the coastal and riverine ecosystems of both developed and developing countries [14].

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The solution to this problem must arise from knowing the state of the inputs and establishing uses that promote the circular economy. Wastewater treatment plants (WWTPs) are typically located at the lowest points in urban areas since sewage systems operate by gravity. This means that the internal purification process requires significant energy with values around 0.4–2.7 kWh/m$^3$ [15]. When WWTPs collect effluents from cities or coastal municipalities, reusing these effluents necessitates higher energy consumption to repurpose the water for alternative uses (mainly irrigation or non-potable urban uses such as street cleaning and/or garden irrigation), including recharging over-exploited aquifers [16]. Mediterranean cities (e.g., Alicante, and Naples, among others) exemplify locations where high volumes of reused water are integrated into secondary uses, necessitating pump systems to distribute the regenerated water [17]. [18] evaluated feasibility procedures for municipal wastewater treatment and their potential for agricultural water reuse, highlighting operational challenges and post-treatment requirements for meeting quality standards. Social Water Cycle (SWC), highlighting its interaction with climate change and human activities was proposed strategies for optimizing water management and enhancing sustainability in developing regions [19]. Enhancing education and awareness is crucial to transforming perceptions and increasing acceptance of sustainable water reuse practices [20]. Consequently, water-reuse projects must be evaluated from economic, technical, and environmental perspectives [21]. These environmental interventions and sustainable development strategies are urgently needed to mitigate the detrimental impacts [22].

Spanish irrigation communities have made substantial efforts to improve their infrastructure, mainly by modernizing their irrigation systems with localized methods [23]. This modernization has made previously uncultivated irrigated areas attractive for agricultural enterprises again, thereby increasing irrigation efficiency [24]. However, the expansion of previously abandoned cultivated land, the need for more water due to climate fluctuations, and the reduced water reserves (such as the Tajo-Segura water transfer) during droughts, have all driven these communities to find ways to integrate new resources into their systems [25]. As example, the irrigation deficit in Mediterranean area could increase around 40 % [26]. This implies that water governance policies and managers should focus on economically viable desalination processes as well as the reuse of wastewater [27]. It can be a great environmental solution, mainly for coastal city centres or large populations, where the regenerated waste water is not used totally, and the regenerated volume is discharged to watercourse or sea. If the water management plans are analysed, a high percentage of this volume could be used for agriculture For example Emirates generated 289 hm$^3$ each year [28], China annually treated around $1.26 \cdot 10^7$ hm$^3$ [29], and Spain generated 4876 hm$^3$ annually and the water reused percentage oscillated between 0 and 91.38 % as a function of the region, with average 10.91 % in the country [30]. These values and the low reused values imply the need to search for new strategies to introduce new resources in the deficit area in the agricultural communities, which are high water consumers [31].

The developed water systems and the proposed need to be able to adapt to these changing patterns [32]. The use of wastewater circular sustainability should try to reach goals, which include maintaining a reliable supply, reducing energy usage, and, when it comes to using reclaimed wastewater, managing the full volume produced by the treatment plant to avoid releasing it into natural water bodies.

This research presents an innovative approach by integrating treated wastewater into agricultural irrigation systems through hybrid technologies. This method demonstrates significant positive impacts on both social and environmental aspects in rural areas, as well as a reduction in sea contamination. The primary aim of this research is to eliminate the discharge of wastewater from treatment plants into the sea. A secondary objective is to redirect this treated water to irrigation systems, thereby alleviating water scarcity and reducing the reliance on aquifers. The third objective is to achieve zero emissions by utilizing renewable energy systems to avoid reliance on the grid.

The document is structured into several sections. The first section provides a review of the state of the art, outlines the main objectives, and highlights the novelty of the manuscript. The second section, titled "Methodology and Materials," is divided into two subsections: Section 2.1 focuses on the development of the proposed methodology, while Section 2.2 describes the case study. The third section covers the analysis and discussion of the results. Finally, the fourth section presents the conclusions, including the limitations of the study and recommendations for future research.

## 2. Methodology and materials

The new strategy is divided into three different blocks. Each block developed an optimisation procedure to reach the aim, transferring the best solution to be optimized in the following step. As a novelty, the proposed methodology includes the possibility to maximise the reuse of the total regenerated volume in the WWTPs, avoiding the sea contamination from the cities and reintroducing these water volumes in rural areas to increase the economic rise in these areas.

### 2.1. Methodology. Optimization stages

Fig. 1 shows the different main blocks to define the optimized strategy. These various blocks are established in three different blocks, called "Block I. Evaluation of restrictions", "Block II. Zero discharge procedure", and "Block III. Social and Environmental Evaluation".

#### 2.1.1. Block I.- Evaluation of restrictions

This first block is responsible for quantitatively establishing the use of the volumes reclaimed by wastewater treatment plants in cities. Step I. A - quantifies the available volume, assesses the quality and considers the negative impact of discharge into watercourses or the sea, mainly patagonic aquatic systems [33]. The possibility of using these resources is based on the fact that there are potential consumers in the vicinity of the wastewater treatment plants that act as sources. There are two potential consumers. The city itself, which consumes water, can consume reclaimed water that is used for street washing and watering green areas [3].

The evaluation of water quality depends on each treatment plant as well as on the process itself. In the case of irrigation water, the quality parameters are of no importance as long as the discharge regulations of the treatment plants are complied with, as these quality parameters have no implications for the crop. Salinity is crucial and depends on the specific treatment plant and its effluents [34]. In this term, there can be two case in which the water allows irrigation because it presents salt conductivity below the planted varieties, since it depends on the crop [35]. In the second case that the salinity is higher than tolerable, the design process of zero discharge must contain a desalination process that allows the mixing of water and obtain a water suitable for irrigation. Therefore, the crop defined the limitations in terms of salinity.

On the other hand, if there are rural centres with agricultural activity, this volume can be used for agricultural purposes. This volume will alleviate the deficit that many areas have as a result of climate change. This new source of water resources when it is considered in the agricultural cycle, can improve agricultural productivity in these areas and therefore avoiding rural depopulation towards the cities [36].

In terms of quantity limitation, the irrigated area to be supplied must guarantee that its irrigation needs are greater than the volume generated by the treatment plant. If this is not the case, the system must incorporate irrigation sink entities that can guarantee that all of the water is reused and not discharged into the sea. In terms of parameters, the historical average flow and its hourly pattern are necessary to optimize the minimum volume of regulation necessary in the system.

If there is the possibility of introducing this volume, the procedure should evaluate the minimal operation constraints considering the

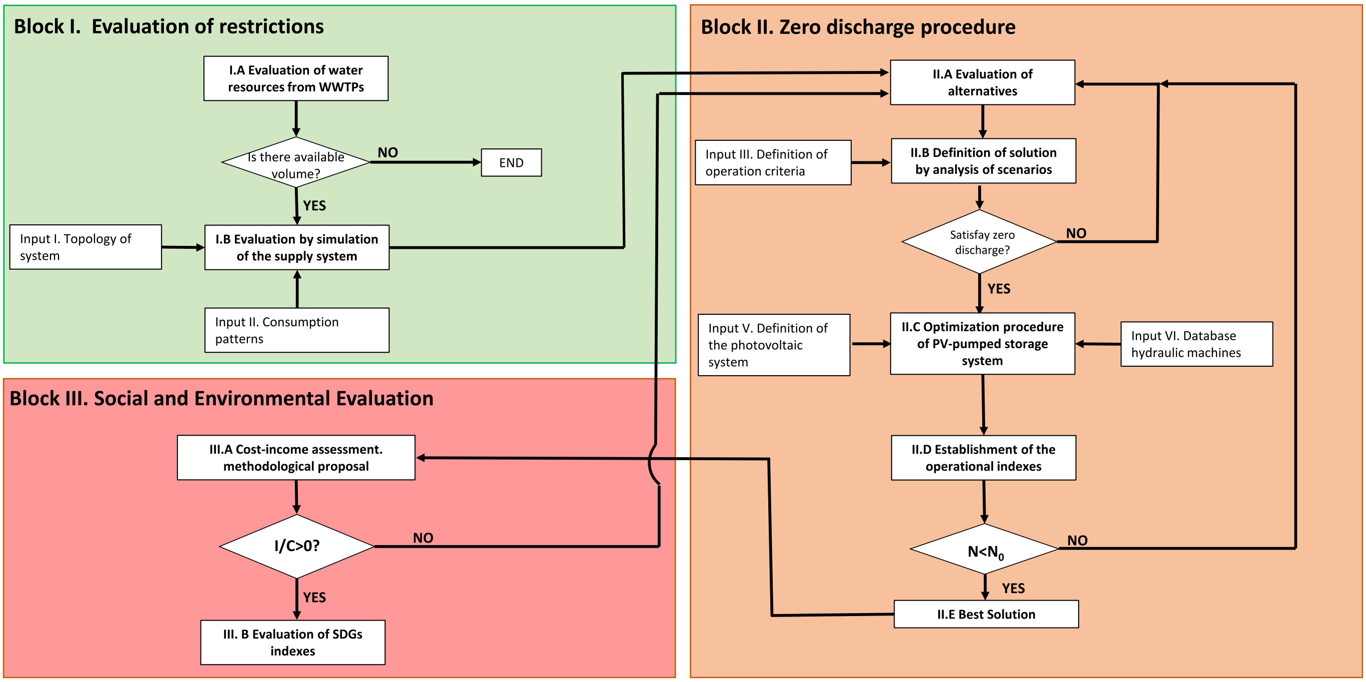



**Fig. 1.** Proposal of the optimization procedure.

available flow from WWTPs (from Step I.A), the topology systems (Input I), and the consumption patterns of the irrigation systems of the rural agricultural (Input II). This basic model is defined using EPANET [37]. Simulating with EPANET is necessary to determine the minimum levels of various reservoirs and tanks required to meet water demand while ensuring the system's minimum pressure. A calibrated methodology defined by [38] facilitates the estimation of the demanded flow at each consumption. The main input data and the results of the zero-discharge optimization are attached in Appendix A.

### *2.1.2. Block II. Zero discharge procedure*

The second block contains the main optimisation module. In this phase, five steps are specified to technically optimize the solution. These are defined in five sub-steps: Step II. A called evaluation of alternatives. The second sub-step (Step II·B) defines the scenarios, which is called the definition of solutions using aggregated scenarios. The third one contains the process of optimisation of hybrid systems (Step II·C). The fourth stage, called Step II·D, deals with the study of operational indexes that allow addressing the correct behaviour of the system defining the zero-discharge concept, and choosing the best technical solution (Step II·D).

The evaluation of alternatives (Step II.A) is established using QGIS routines [39] that, according to the restrictions defined in the previous assessment (Block I), establish the minimum piezometric and reservoir location requirements that allow regulating the volumes coming from the WWTPs by definition of the criteria (Input III). Besides, the alternatives should consider the osmosis procedure since the coastal cities are characterized by higher values of salinization due to intrusion marine. This particularity avoids the a directly use of irrigation. It implies each alternative contains the osmosis process, which is mixed with water from the treatment plant to achieve the desired mixture. This water mix enables the circular water use of these resources.

Any alternative should guarantee the mass balance, which is defined by the following expression:

$$V_{WWTP} = V_{OP} + V_{WOP} + V_{RF} + V_{ROP} \quad (1)$$

where $V_{WWTP}$ is the annual volume from wastewater treatment plants in m$^3$; $V_{OP}$ is the annual volume from the osmosis procedure in m$^3$; $V_{WOP}$ is the annual volume, which is used directly from WWTP without the osmosis procedure in m$^3$; $V_{RF}$ is the annual volume, which is rejected from the filtration procedure and is recirculated in the system in m$^3$; $V_{ROP}$ is the annual volume, which is rejected from the osmosis procedure and it is derived to artificial wetlands for biological treatment and natural restitution for nature-safe disposal in m$^3$ [40].

The annual available water volume ($V_{AWV}$) to be introduced in the circular water sustainability from cities to rural areas is defined by the following expression:

$$V_{AWV} = V_{OP} + V_{WOP} \quad (2)$$

Step II·B is a previous stage to the optimized energy procedure. This step aims at the generation of the different scenarios, which are defined by user demand, and the consumption patterns of users. To operate the optimization procedure defines two indexes called demand index (*DI*) and demand transferred index (*DTI*). Both indexes are defined by the following expressions:

$$DI = \frac{\sum (V_{d,i} \cdot H_d)}{V_t \cdot 10} \quad (3)$$

where $V_{d,i}$ is the demanded volume for consumption point *d* by the user *i*. It is established by the following equation:

$$V_{d,i} = k_{d,i} \cdot V_{d,total} \quad (4)$$

where $k_{d,i}$ is the distribution coefficient according to the demand distribution hypothesis; $V_{d,total}$ is the total volume of the demand for the consumption point *d*; $H_d$ is the hypothesis for the consumption point *d* to the demand situation considered in the calculation scenario, its value varies between 0 and 10; $V_t$ is the total demanded volume by the system defined as

$$V_t = \sum V_{d,i} \quad (5)$$

*DI* values range from 0 to 1. When *DI* is equal to 0, it indicates that all demand points operate under hypothesis $H_0$ (24-h annual average). A *DI* value of 1 means that all demand points operate under hypothesis $H_{10}$ (monthly average at 20-h). Intermediate values represent other methods of delivering the demanded volumes.

*DTI* to $R_j$ is defined as the ratio between the difference in volumes supplied from $\sum R_j$ (where $j$ represents the different reservoirs considered in the system) and the volume demanded by the consumption points upstream of them, relative to their minimum difference.

$$DTI = \frac{V_{\sum R_j} - V_{d,i}}{\left(V_{\sum R_j} - V_{d,i}\right)_{min}} \tag{6}$$

*DTI* represents the increase in volumes that are redistributed from the demand $d_i$ to entities at higher elevations, which must be transferred by pumped systems from downstream reservoirs $(R_j)$. *DTI* is always greater than or equal to 1, and its maximum value depends on the sum of $\sum R_j$ and $V_{d,i}$.

Step II·C is the main optimization procedure shown in Fig. 2. The strategy is divided into seven sub-phases that aim to find feasible solutions that allow the guarantee of zero discharge, and between them to optimize according to the set variables ($F$) and taking into account the operating rules. Furthermore, the methodology relies on the provision of the necessary hydraulic machines (pumps and/or turbines) as well as the analysis of photovoltaic generation in terms of guaranteeing zero energy consumption from the grid.

The method considers different variables (Stage II·C.1) based on their constraints of the hydraulic model (Step I·B). In this case, the system operates with three other variables, defined as $F$, (i.e., pumped flow, volume of reservoirs and photovoltaic power to be installed). The solutions are chosen within the ranges of flow rates, installed power and reservoir volume, and solutions are calculated, the unfeasible ones are discarded and the pumping stations with minimum energy requirements are designed within the best solutions.

The variables of Step II·C are: $Q_{pm}$ is the pumped flow for interval $m$ in $m^3/s$; $H_{pm}$ is the maxim of $(P_{om,min}-P_{om})$ for $o = 1$ to $O$ in mw.c.; $O$ is the number of nodes of the pumped system; $P_{om,min}$ is the minimum pressure of service required in the most disadvantageous node for interval $m$ in mw.c.; $P_{om}$ is the pressure in the most disadvantageous node for interval $m$ in mw.c.; and $Q_c$ is the flow rate between pumps in $m^3/s$.

The ranges for the flow rate are defined between minimum flow rate (possibly the months of highest radiation) and max flow rate (lowest radiation). Power variable according to the surface on which it can be installed and the maximum height to be lifted. The volumes of reservoirs depend on the topographical conditions.

Sub-phase II.C.2 defines the operation rules defined in the proposed algorithm in terms of pumped stations, hydropower stations and

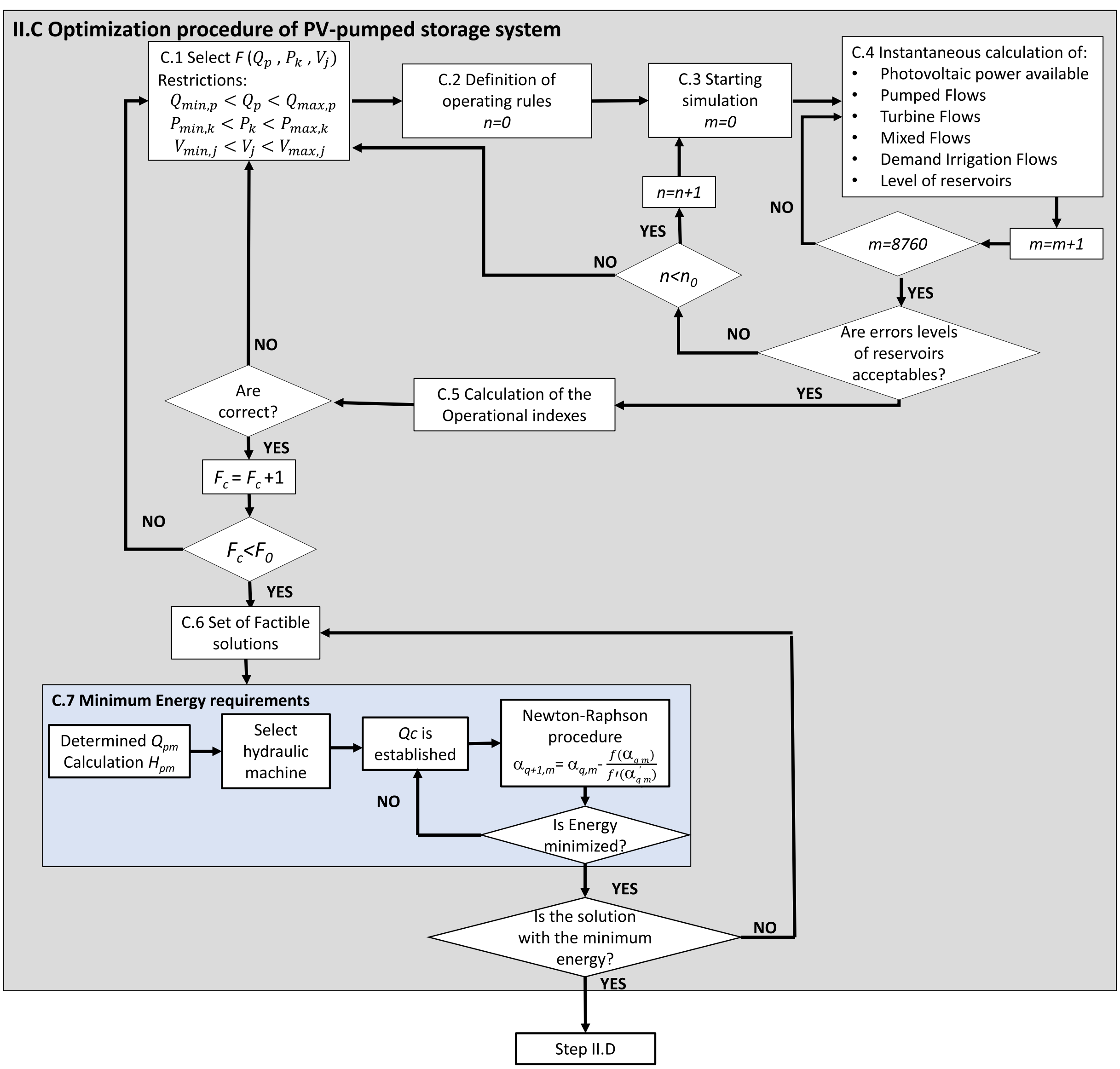



**Fig. 2.** Optimization procedure for each analysed scenario.

reservoir levels to develop the first iteration (II.C.3) considering the mass and energy balances in terms of pumped flow, turbine flow, available solar energy, mixed flow to guarantee the quality in the desalination procedure, among others in sub-stage II.C.4. The procedure addresses an iterative development of annual ($n$) calculations that address the periodic stabilisation of the overall system, in terms of mass balances in all the reservoirs involved in the process. The system also evaluates the uncertainty within the process in the face of the variability of the parameters, mainly the variation of the demands. This analysis aims to know the system's response in non-stationary design situations. In the non-stationary situations, the error level is not evaluated. When the stationary situation is analysed the error between water mass balance must be zero, running the procedure until step II.C.5.

Sub-phase II.C.5 evaluates the different technical indexes according to technical, economic and environmental values. Different individual indexes are considered, defining capacity ratio, distributed volume ratio and distribution ratio.

Capacity Ratio ($CR$): Its purpose is to assess whether the basins in the system are oversized. The range is from 0 to 1. Values near zero suggest that the reservoir being studied is oversized, while values near one indicate that it is optimized for regulation in the analysed scenarios. The Capacity Ratio is a technical index for each reservoir and it is defined as follows:

$$CR = \frac{C_{theoretical}}{C_{defined}} \tag{7}$$

where $C_{theoretical}$ is the necessary capacity in $m^3$ for each scenario and $C_{defined}$ is the evaluated capacity in the simulation in $m^3$. When all reservoirs are considered, the procedure can define the global capacity ratio ($GCR$).

Distributed Volume Ratio (DVR): This is the index that shows for each scenario the compliance or non-compliance with the zero-discharge strategy, ensuring the environmental objective of the strategy. It can oscillate between 0 and 1. The best value is 1.

$$DVR = 1 - \frac{V_{NES}}{V_{wwT}} \tag{8}$$

where $V_{NES}$ is the volume discharged to sea not reused in rural areas; $V_{wwT}$ is the total volume generated by WWTP in $m^3$.

Distribution Ratio (DR): It corresponds to a social technical index of system operation that establishes the capacity to distribute the necessary volume to the demand. Its objective is to measure the degree of supply of the demanded volume in a dimensionless manner according to the established scenario. It takes into account the volume that the system has not been able to deliver to the demands ($V_{NDV}$) and the volume that it should theoretically deliver according to the calculation scenario ($V_{DTV}$). It takes values between 0 and 1, with the ideal value being 1 because it guarantees that all the demand of the calculation scenario is supplied. It is defined as:

$$DR = 1 - \frac{V_{NDV}}{V_{DTV}} \tag{9}$$

when all demands are considered, introducing the different volumes, the Global Distribution Ratio (GDR) can be defined.

If the indexes are correct, the solution is considered feasible ($F_c$), defining the system's new sets of solutions ($F$) iteratively until the maximum number of corrected solutions ($F_0$) is completed (step II.C.6). The latter depends on the applications of the case study as well as reservoir location and system operation constraints.

When all different solution sets are developed, the iterative optimization methodology applies the Newton-Raphson algorithm [41] to address the minimization of energy consumption in pumping stations, an iterative regulation strategy is based on the Newton-Raphson optimization method [42]. This method optimized the rotational speed to minimize the flow and pressure requirements. The head and efficiency curves for the pump machine are defined by the following equations:

$$H = \alpha\left(A + B\frac{Q}{\alpha} + C\frac{Q^2}{\alpha^2}\right) \tag{10}$$

$$\eta = E_4\frac{Q^4}{\alpha^4} + E_3\frac{Q^3}{\alpha^3} + E_2\frac{Q^2}{\alpha^2} + E_1\frac{Q}{\alpha} + E_0 \tag{11}$$

where α is the ratio between rotational speed and the nominal rotational speed, $Q$ is the flow rate in $m^3/s$; $H$ is the pumped head for a given rotational speed in m w.c. and $\eta$ is the efficiency of the machine and $n$ is the number of installed pumps machines. $A$, $B$, $C$, $E_4$, $E_3$, $E_2$, $E_1$ and $E_0$ define the characteristics curves provided by the manufacters.

The instantaneous power is defined by

$$P = \gamma g n_0 Q H \eta \tag{12}$$

where γ is the specific weighted $kN/m^3$, $g$ acceleration of gravity in $m/s^2$ and $n_0$ number of operating machines. The optimization procedure reaches de best operational points of the machine in terms of energy requirements for each interval $k$ by minimizing instantaneous power requirements by iterative regulation strategy based on the Newton-Raphson optimization method [42]. For each interval, the α value is calculated to optimize the pump operation points, determining the optimal number of machines ($n$) and establishing a flow rate between pumps, when in the system are two or more pumps. The optimization procedure is subject to the following restrictions: $0.75 \leq \alpha \leq 1.25$ and $1 \leq n_0 \leq N$, where $N$ is the maximum number of machines in pumping station analysed.

In addition, it internally addresses a sensitivity analysis for the solutions, aiming to know their influence on the final result.

Step II·D deals with the analysis of global operation indicators once the system has optimized the minimisation of system energy, guaranteeing their operability. For this purpose, the use of different indicators is defined. Different expressions of variables are described in Tables A.1-A.4 and Fig. A.1 of Appendix A. The indicators are defined as follows:

- Manometric Regulation Ratio ($MRR$) evaluates the relation between the pumped volume and the distributed volume. Its ideal value is 1, but if there are different pumped units, the value is always above 1.

$$MRR\ (-) = \frac{\sum_{p=1}^{P}\sum_{m=1}^{8760} H_{pm}V_{pm}}{\sum_{j=1}^{J}\sum_{m=1}^{8760} H_{jm}V_{jm}} \tag{13}$$

where $p$ is each of the pumping stations; $H_{pm}$ is the manometric head of pumping in each hour m in m w.c.; $V_{pm}$ is the volume pumped in hour $m$ in $m^3$; $H_{jm}$ is the piezometric level of reservoir $j$ concerning the level of the WWTP in hour $m$ in $m^3$; $V_{jm}$ is the volume distributed in reservoir $j$ in hour $m$ in $m^3$.

- Energy Distribution Ratio ($EDRp$) determines the ratio between the energy consumed by each pumping system ($p$) in each analysed scenario and the maximum energy consumed by the system. This reveals the proportion of energy each pumping system uses to operate, varying between 0 and 1.

$$EDRp = \frac{E_{SI_{ps}}}{E_{p,max}} \tag{14}$$

where $E_{SI_{ps}}$ is the energy consumed in pumping system $p$ analysed in each of the scenarios studied ($s$) in kWh; $E_{p,max}$ is the maximum energy consumed in any of the scenarios for $p$ pumping system.

- Distributed Energy Consumption Ratio (*DECR*) defines the ratio between consumed energy and the water-distributed volume.

$$DECR\left(\frac{kWh}{m^3}\right) = \frac{Consumed\ Energy\ (kWh)}{Distributed\ volume\ (m^3)} \quad (15)$$

- Used Generated Power Ratio (*UGPR*)index defines the relationship between the installed solar power in Wp and the distributed volume of the system. The minimization of the value established the best solution, according to installed photovoltaic system.

$$UGPR\left(\frac{Wp}{m^3}\right) = \frac{Installed\ Solar\ Power\ (Wp)}{Distributed\ volume\ (m^3)} \quad (16)$$

- Levelized Cost Value (*LCOE*), is defined to size the best diameter of the different pipes of the systems.

$$LCOE\left(\frac{€}{kWh}\right) = \frac{IC_0 + \sum_{t=1}^{t=T} \frac{AC_t}{(1+k_{RD})^t}}{\sum_{t=1}^{t=T} \frac{E_t}{(1+k_{RD})^t}} \quad (17)$$

where $IC_0$ is the initial investment in € in the year 0. It studies the investment of the grid facilities to reach the supply points; $AC_t$ is the operation and maintenance costs in € for the year *t*; $E_t$ is the annual energy in kWh for the year *t*; *T* is the lifetime in years, considering 25 years; $k_{RD}$ is the real discount rate, in this study is considered 0.04 according to [43].

- Energy Recovered Ratio (*ERRr*) establishes the ratio between the energy recovered by each micro hydropower for each of the scenarios analysed and the maximum recovered energy by the system in the best scenario. It therefore shows the proportion of recovered energy consumed that each of the pumping systems use to operate.

$$EER_r = \frac{E_{rs}}{E_{r,max}} \quad (18)$$

where *r* is the recovery system under study, $E_{rs}$ is the total recovered energy in scenario *s* in the system *r* in kWh, $E_{r,max}$ is the maximum recovered energy in system *r* in the all analysed scenarios in kWh.

- Power Consumption Ratio (*PCRp*)establishes the ratio between the maximum power consumed by each pumping system for each of the scenarios analysed and the maximum power consumed by the system. It therefore shows the proportion of power consumed that each of the pumping systems uses to operate.

$$PCR_p = \frac{P_{ps}}{P_{p,max}} \quad (19)$$

where *p* is the pumping station under study, $P_{ps}$ is the maximum power consumed in scenario *s* in kW for *p* pumping station, $P_{p,max}$ is the maximum power consumed in system *p* in the all analysed scenarios in kW.

### 2.1.3. Block III. Social and environmental evaluation

The third block of the methodology is in charge of evaluating the social and environmental impact of the circular water proposal in terms of sustainability through indicators, showing the effects of the zero-discharge strategy in cities and rural areas.

The cost-benefit analysis is developed to evaluate and compare the advantages and disadvantages of a project, considering the investment to be made and the technical and social benefits derived from the project [44]. Benefits are assessed about the associated costs within a common analytical framework, with clearly established spatial and temporal boundaries. As these costs and benefits are linked to various impacts measured in different units, a monetary value is used as a common denominator to facilitate meaningful comparison [45].

Fig. 3 shows the responses and results resulting from incorporating wastewater from zero-discharge projects.

All the proposed indices are based on references and/or evaluations. The description of each one encompasses the associated terms and cost-benefit analysis. Regarding the component of restoration, health impact, and water quality improvement, specifically the reduction of discharges into rivers and seas, through the nitrogen (N) and phosphorus (P) reduction index and the elimination of water discharge, they economically estimate the impact on health, environmental restoration, and water quality improvement. Other indexes focused on the benefits of increased employment, desertification or CO2 emission also include indirectly the positive impact on the health population.

The assessment of the different direct and indirect results can be addressed through the following indicators:

*Investment and maintenance costs (EAC)*: The operating costs of water infrastructure investments generally include energy, materials, services, technical and administrative staff, as well as maintenance. This cost can be established according to the following expression, as defined by [45].

$$EAC = \frac{r(1+k_{RD})^T}{(1+k_{RD})^T - 1} I + OMC \quad (20)$$

where *EAC* is the annual equivalent cost in €/year; *T* is the number of years, considering 25 according to [24]; $k_{RD}$ is the real discount rate, considering 4 % according to [43]; *I* is the investment costs in €; *OMC* is the operation and maintenance costs (€/year).

*Benefit Productivity Increase (BIP):* Water productivity is established by addressing its use in localized irrigation systems. This fact establishes that combining the cumulative effects is related to increasing the added value of the crop and improving the efficiency of its use [46]. When the case study is analysed, particularized in the rural areas of Alicante and Murcia, the *BIP* coefficient is equal to 1.01 €/$m^3$ [44]. *BIP* is defined by the following expression:

$$BIP = 1.01\ 10^6\ V_{AWV} \quad (21)$$

where *BIP* is the benefit due to increased productivity in €/year; $V_{AWV}$ is the volume incorporated annually into the system in $hm^3$, which is currently not reused. This volume is evaluated from Block I.

*Desertification Reduction Benefit (DRB)*: In addition to improving the indicators of sustainability and vulnerability concerning desertification, the incorporation of water resources that mitigate the reduction due to the extraction of bodies of groundwater and/or from transfers from other basins allows the irrigated surface area to be maintained. For this reason, the incorporation of these resources makes it possible to maintain the cultivated areas that carry out $CO_2$ capture tasks. In this case, an average fixation of 13.2 t$CO_2$/ha of crop is established for the typical crops in the study area, which are focused on vegetables, citrus and stone fruit trees [47].

$$CO2\ fixed\ social\ profit\ (FSP) = FF_{CO_2} S_{supplied}\ SC_{CO_2} \quad (22)$$

where *DRB* is the social benefit for CO2 fixation by maintaining the irrigated area by FSP indicator; $FF_{CO_2}$is the average CO2 fixation factor established by [47]; $S_{supplied}$ is the cultivated area in the area considered that allows supplying the average irrigation needs of the area in $m^3$/year considering the annual incorporated volume ($V_{AWV}$) in $hm^3$. The average endowment (*AE*) is defined in the different management plans defined by [48] in $m^3$/ha; $SC_{CO_2}$ is the social cost equal to 43€/t$CO_2$ [49].

$$S_{supplied}(ha) = \frac{V_{AWV}}{AE}\ 10^6 \quad (23)$$

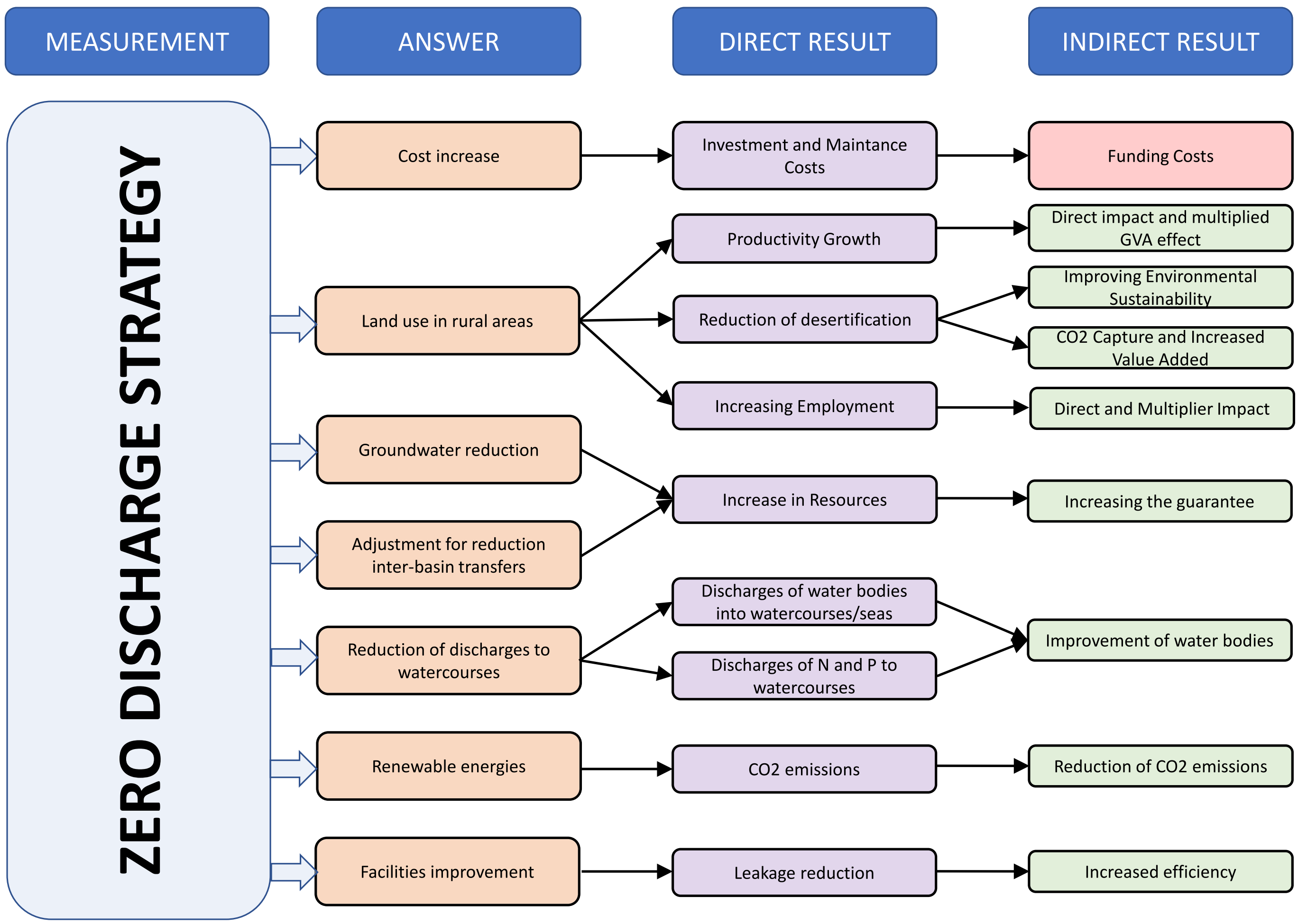



**Fig. 3.** Social, environmental and economic measures and responses of the zero-discharge strategy.

*Benefit increased employment (BIE)*: Guaranteeing the supply of water resources and dispelling the uncertainty of access to them is crucial to maintaining agricultural activity. In this case, in the province of Alicante, the agricultural sector accounts for 1.8 % of gross value added (GVA) and 3.7 % of employment [50]. Taking the reference value of job destruction as a function of the deficit of the Tajo-Segura water transfer, concerning the established volume of 400 $hm^3$ per year, an employment coefficient (EC) equal to 20.51 jobs/$hm^3$ is considered [44]. Therefore, maintaining the non-agricultural proportion (4 to 1) according to [50], and taking as a reference the average productivity of agricultural labour for the Valencian Community equal to 37,717 €/worker in the agricultural sector and 51,475 €/worker for the rest of the economy according to [51]. Therefore, the *BIE* can be determined as follows:

$$BIE = EC\ V_{AWV}\left(\frac{4}{5}\ 37717 + \frac{1}{5}51475\right) \quad (24)$$

where *BIE* is the benefit due to increased employment in €/year; *EC* is the employment multiplier coefficient considering 20.51 jobs/$hm^3$; $V_{AWV}$ is the annual volume incorporated that is currently not reused in the system in $hm^3$.

*Incremental Guarantee Benefit (IGB)*: Security of supply is crucial for the maintenance of cultivated areas. Reducing the uncertainty of resource availability allows companies in the sector to develop long-term action plans. The introduction of this volume allows the system to generate income from the value of its sale. In this case, an average price of 0.3 €/$m^3$ is considered, although depending on the origin of the resource, water prices in the study area differ according to [52]. In this case, the annual *IGB* will be established by the expression:

$$IGB = 0.3\ 10^6\ V_{AWR} \quad (25)$$

where IGB is the benefit due to increased security of supply in €/year.

*Water Bodies Improvement Benefit (WBIB)*: The fact that guaranteeing zero-discharge has a positive impact on the overall water resource systems as a result of the reduction in the extraction of groundwater bodies and/or makes it possible to mitigate the reduction in transfers between basins, such as the Tajo-Segura by its exploitation rules. This index enable the estimation of the improvement of the restauration of the water quality as well as the.

The use of wastewater allows an evaluation to be made of the shadow prices derived from the discharge of this water into natural areas. In this case, 0.1 €/$m^3$ and 0.7 €/$m^3$ are considered for discharges into the sea or river, respectively [53]. Therefore, the benefit is established according to the expression:

$$WBIB = DC\ V_{AWR}\ 10^6 \quad (26)$$

where *WBIB* is the benefit of improving water bodies in €/year; *DC* is the discharge cost by destination [53].

*Nitrogen Reduction Improvement (NRI)*: In some cases, the reduction of N from water by removing it through biological processes can be envisaged. The measure causes a benefit to the status of water bodies in general by reducing N pollution and thus vulnerability. This benefit can be expressed as follows:

$$NRI = NRC\ C_N\ V_{ROP} \quad (27)$$

where *NRI* is the benefit of improvement of water bodies as a consequence of N reduction in €/year; *NRC* is the cost of removal in ecological systems equal to 0.208 €/kg according to [54], $C_N$ is the concentration of N removed from the system in kg/m$^3$; $V_{ROP}$ is Annual volume, which is rejected from the osmosis procedure and it is derived to artificial wetlands for biological treatment and natural restitution for nature-safe disposal. Its units are m$^3$. This benefit is only considered in systems that have introduced green filter systems to address salt removal.

*Clean Energy Emission Benefit Generation (CEE)*: The estimated value of $CO_2$ generation from energy use is set at 404gCO2/kWh ($G_{CO_2}$)

$$CEE = KG_{CO_2}E_cSC_{CO_2} \quad (28)$$

where *CEE* is the social benefit of not generating CO2 with energy consumed from the grid; *K* is the coefficient that weights the difference between 100 % use of renewable energy (project) and the average renewable energy that supplies the Spanish electricity grid, which corresponds to 50 % in 2023 according to [55,56], growing by 30 % compared to 2022 for 2024. Therefore, on the security side, K is considered equal to 0.4; $G_{CO_2}$ is the CO2 value per energy consumed; $E_c$ is the annual energy consumed by the system in kWh; $SC_{CO_2}$ is the social cost equal to 43€/kgCO2 [49].

*Leakage Reduction Improvement (LRI):* The solution can replace totally or partially obsolete facilities that have a high percentage of leaks or which, due to the frequency of breakages, do not allow a continuous transfer of volumes to be maintained. Breakage implies the impossibility of guaranteeing zero-discharge, while leakage means that the water collected in the WWTP cannot be distributed by the irrigation communities and therefore productivity and guarantees are lost. For this reason, the same average guarantee price is considered, when making volume available to the user. In this case, the benefit due to the reduction of leakage is established as follows:

$$LRI = 0.3\ 10^6\ LR\ V_{LR} \quad (29)$$

where *LRI* is the benefit due to increased security of supply in €/year; *LR* is the leakage rate considering an estimated average value equal to 0.31 [57], $V_{LR}$ is the leak-reduced volume currently flowing through pipelines in the leaking system in hm$^3$ each year.

*Economic multiplier effect (EME):* Looking at the growth of the agricultural sector, it produces a multiplier effect on industry [45]. This growth is set to a factor of 0.49 $F_{ME}$ according to [58], which was considered in the evaluation of irrigation modernisation by [45].

This economic multiplier effect (*EME*) will be defined by the expression

$$EME = F_{ME}\ RS\ GVA_{AS} \quad (30)$$

where $GVA_{AS}$corresponds to the gross value added of agriculture in the province of Alicante, considered equal to 657,106 € [50] and *SR* corresponds to the surface ratio of the benefited area ($S_b$) to the total area devoted to agriculture in Alicante ($S_{Alicante}$), which is 184,243.3 ha according to defined as follows:

$$SR = \frac{S_b}{S_{Alicante}} \quad (31)$$

The positive assessment of the cost-benefit ratio (*B/C*) allows us to address step III·B which encompasses the analysis or influence of some of the *SDG* targets. The *B/C* ratio is defined as

$$\frac{B}{C} = \frac{\sum Beneficits + EME}{EAC} \quad (32)$$

To know the real impact of the strategy three different *B/C* are considered: (i) *B/C Global*, it considers all defined indexes previously; (ii) *B/C without EME and CEE* defined as minimum *B/C*. It measures the real impact of the strategy in the water resources, without considering the economic effect (*EME*) and the positive use of renewable energies (*CEE*); (iii) *B/C without CEE*, this indicator measures the impact of the strategy without considering the positive effect of the use of clean energies. In all cases, when *B/C* is above 1, the investment is considered viable.

### 2.2. Case study. Wastewater treatment plants in Alicante City, Spain

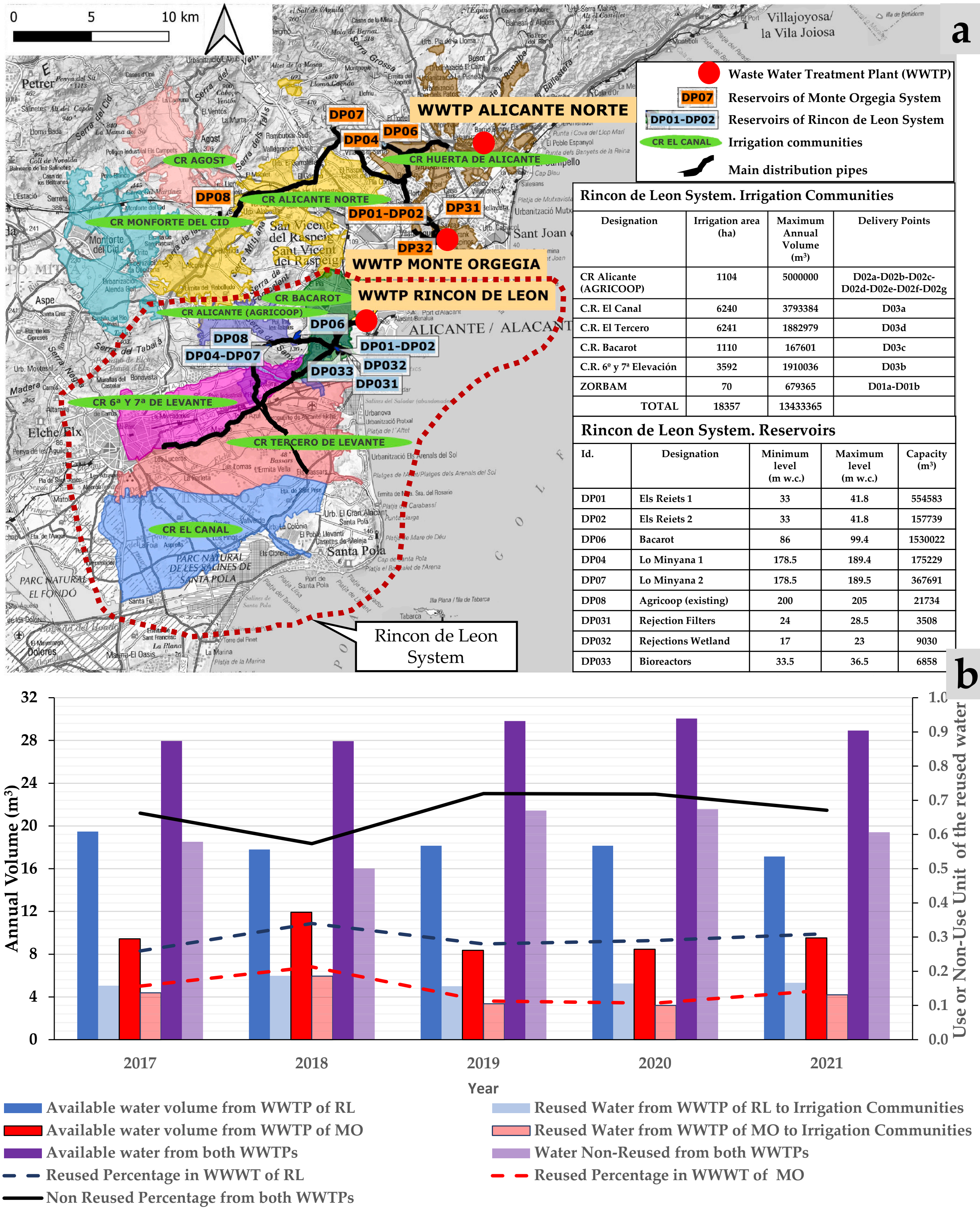
The methodological proposal was applied in two of the three wastewater treatment plants in Alicante, Spain (Fig. 4a). These three treatment plants are Rincón de León, Monte Orgegia and Alicante Norte. The annual regenerated volume in the third one is 2 hm$^3$. This volume is totally used by the irrigation communities currently. Rincón de León and Monte Orgegia do not use all available regenerated wastewater each year. If the methodology is applied, nine irrigation communities can integrate new water resources into their balance, improving the irrigation deficit of 18,357 ha, being the main crops: table grapes, orange trees, vegetables and almond trees.

Fig. 4b shows the annual volume generated by both WWTPs, which reached an annual average equal to 28.9 hm$^3$ between 2017 and 2021. This volume is only used by the irrigation communities around 9.7 hm$^3$ each year. It implies around 68.9 % is discharged to the sea. The methodology proposed the strategy to use this annual available volume totally in the irrigation communities by an integrated pumped-solar storage distribution system (Fig. 5a). The solar pumping system powered by photovoltaic systems as well as pumped-storage hydropower guarantees a continuous operation that (i) to guarantee the zero-discharge concepts, avoiding the discharge of treated water into the sea as well as its pollution; (ii) to regulate the volumes according to the annual irrigation demand, taking into account the continuity of the flows discharged by the WWTP and the demand for seasonal irrigation of crops; (ii) to incorporate renewable energies that feed the system, guaranteeing no CO2 emissions and reducing the carbon footprint; and (iv) to increase the positive environmental and social impact of the affected areas that currently have problems of pollution from discharges into the sea (coastal cities) and rural agricultural areas that have a water deficit and do not have a guaranteed supply.

The system is designed with two photovoltaic generators (a main called PVG01 and a secondary one, PVG02). These generators are responsible for generating the photovoltaic energy needed to power the different pumping stations. The first of them, PS00 (it is uniquely connected to the power grid system but its consumption is compensated with the excess of photovoltaic generated energy in the proposal), is the one that supplies from the WWTP to the raw water receiving reservoir (DP01). From here there is a system called PS01, which drives to the DP04 reservoir, taking advantage of the excess energy of the system. DP04 acts as a potential energy store to recover energy when there is no solar radiation through the RS01 system, supplying the PS02 pumping system. This system is responsible for imposing the previously osmosed volumes according to the established mixture depending on the desired quality through osmosis.

The osmotised water is stored in the DP02 pond, mixing with raw water from the DP01 pond, achieving the required quality. The PS02 pumping ends in the DP06 pond. In this regulating reservoir it is distributed to different entities by gravity and part of it is pumped to the DP07 pond (PS03 pumping system), which distributes to other entities by gravity and has the last pumping system PS04 to the DP08 pond, which is diverted to another irrigation entity. The rest of the impulsions and tanks (DP03) are auxiliary pumped stations that allow the products derived from filtration to be treated so that they can return to the system and from the rejection of the osmosis to be derived to the wetland and treated so that they can be discharged into the watercourse in terms of sufficient quality.

Fig. 5b shows the distribution of design volumes with which the proposed strategy, should be satisfied to guarantee the zero-discharge strategy of discharge to the sea, maximising the volume reincorporated into the irrigation communities as new resources not used until




Rincon de Leon System. Irrigation Communities

| Designation | Irrigation area (ha) | Maximum Annual Volume (m³) | Delivery Points |
|---|---|---|---|
| CR Alicante (AGRICOOP) | 1104 | 5000000 | D02a-D02b-D02c-D02d-D02e-D02f-D02g |
| C.R. El Canal | 6240 | 3793384 | D03a |
| C.R. El Tercero | 6241 | 1882979 | D03d |
| C.R. Bacarot | 1110 | 167601 | D03c |
| C.R. 6º y 7ª Elevación | 3592 | 1910036 | D03b |
| ZORBAM | 70 | 679365 | D01a-D01b |
| TOTAL | 18357 | 13433365 | |

Rincon de Leon System. Reservoirs

| Id. | Designation | Minimum level (m w.c.) | Maximum level (m w.c.) | Capacity (m³) |
|---|---|---|---|---|
| DP01 | Els Reiets 1 | 33 | 41.8 | 554583 |
| DP02 | Els Reiets 2 | 33 | 41.8 | 157739 |
| DP06 | Bacarot | 86 | 99.4 | 1530022 |
| DP04 | Lo Minyana 1 | 178.5 | 189.4 | 175229 |
| DP07 | Lo Minyana 2 | 178.5 | 189.5 | 367691 |
| DP08 | Agricoop (existing) | 200 | 205 | 21734 |
| DP031 | Rejection Filters | 24 | 28.5 | 3508 |
| DP032 | Rejections Wetland | 17 | 23 | 9030 |
| DP033 | Bioreactors | 33.5 | 36.5 | 6858 |

**Fig. 4.** Hydraulic system (a); Annual available and reused volume from WWTPs (b).

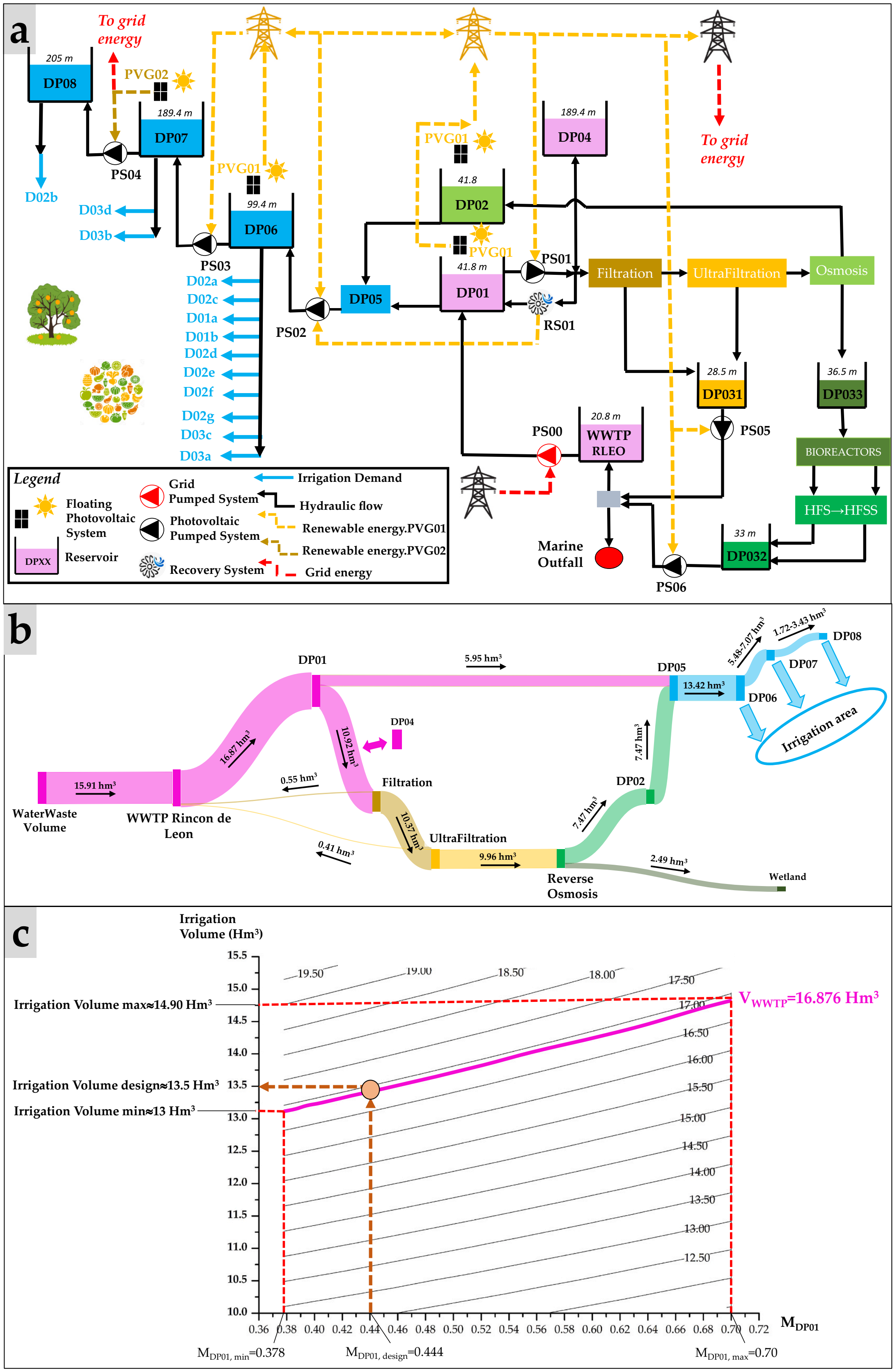



**Fig. 5.** Scheme of system (a); Mass balance of zero-discharge strategy in Rincon de Leon System (b); Irrigation volume as a function of the mixed flow (c).

now. Fig. 5c shows, depending on the salinity of the water from the sewerage system of the city of Alicante and San Vicente del Raspeig, the volume of irrigation water available as a function of the gross volume entering the *WWTP* and the mixing coefficient (*M*) necessary to guarantee water of satisfactory quality for irrigation in terms of salinity and nutrient concentration.

## 3. Results and discussion

Considering the previous bases for action set out in the last section on materials, where the existence of unused volumes from the *WWTP* which are being discharged into the sea (Block I) is highlighted. Table 1 shows the different alternatives (Step II.A) that are established corresponding to the possible locations of the reservoirs, pumping flow rates in the various schemes, and the installed photovoltaic power. The iterative procedure considers the values according to the available surface, minimum flows as well as the required surface of the floating photovoltaic system.

Within each alternative evaluated, scenarios are studied considering the variation of the demand index (*DI*) and demand transfer index (*DTI*) (Step II·B). If the zero-discharge target is met, optimisation of pumping systems, photovoltaic systems, micro-hydro plants and optimisation of pipe diameters is carried out (Step II.C). Analysing these alternatives allows the definition of feasible solutions according to the different technical indicators proposed (Step II·D). Fig. 6 shows the values of the different indicators for each alternative.

The primary innovation of this study lies in the implementation of a zero-discharge strategy since there were published research developed proposal to use but anyone defined procedure to guarantee the zero-discharge to sea [28]. The results demonstrate that the proposed methodology adheres to the constraints and objectives established in this research. Rather than comparing it to alternative approaches, the discussion highlights that the technical, energy, and environmental performance indicators meet or exceed those reported in similar studies within the renewable energy and hydraulic sectors.

Fig. 6a shows the Global Distribution Ratio (*GDR*) oscillated between 0.9 and 1 for all alternatives (Id) except Alternative 5 (Id between 10 and 12), which oscillated around 0.5. Similar values showed the Distribution Volume Ratio (*DVR*), which establishes the guarantee of zero-discharge when *DVR* is equal to 1. Fig. 6b shows a detailed of these values without consider alternative 5, which was considered not feasible. Id 1 shows the best values of *GDR* and *DVR*, which considering the different 363 generated scenarios considering different values of *DI* and *DTI*.

Fig. 6c shows the variation of manometric regulation ratio (*MMR*) for the different alternatives defined in Table 1. *MMR* oscillated between 2.42 and 2.74 for all alternatives. A similar trend showed the different alternatives since the higher volume is distributed from a reservoir called DP06. The variation of the used generated power ratio (*UPGR*) for the different alternatives established values around 0.95 Wp/m$^3$, although Id 5, 6 and 9 established values equal to 1.15, 1.27 and 1.36 Wp/m$^3$, respectively. It defined that the photovoltaic unit power was between 21 and 43.1 % higher to distribute the same value. Therefore, these alternatives were rejected to the solution.

Fig. 6d shows the Distributed Energy Consumption Ratio (*DECR*), establishing values between 0.85 and 0.98 kWh/m$^3$. These values improved the reviewed values by [59] that was defined between 1 and 2.5 kWh/m$^3$. Id 4, 5 and 6 showed higher values compared to Id 1. Finally, the global capacity ratio (*GCR*) established the correct volume definition of the different alternatives defining the operation range as a function of the evaluated scenario. Id 1 established values between 0.64 and 0.88.

Fig. 7a shows the integration of the energy demands as well as the generated power by renewable systems (i.e., photovoltaic and micro hydropower, which take advantage of the excess of photovoltaic energy to pump to reservoir DP04 and this potential energy is used to operate with pump working as turbines when there is no solar radiation. Fig. 7a and b show the difference between the summer and winter seasons, which defined the optimization of the hybrid systems to generate energy to guarantee zero discharge.

Fig. 7c shows an example of the global energy balance. It shows the annual consumed energy by the pumped systems (Red colour and negative value because it is injected in the system), the annual cumulative generated energy by the photovoltaic system (yellow colour and it is positive because it is generated), the annual cumulative hydraulic energy (blue colour) it is lower than photovoltaic system but it enables the operation of the system when there is not solar radiation and therefore, it enables the continuous operation of the system. Finally, a green line defines the positive balance between generated and consumed energy. The excess energy is fed back into the grid to offset the energy consumed in the wastewater treatment plants, ensuring a net energy balance. Fig. 7d shows the CO2 tonnes non-emitted to the atmosphere to use the renewable hybrid solution to operate in the system, reaching around 7500 t each year. This figure demonstrates the self-consumption of the procedure developed, guarantee the green circular management of the distribution system [60].

Fig. 8 shows the evaluation of the best solution for the different *DI* and *DTI*. Fig. 8a establishes the energy recovered ratio (*ERR*) of the micro-hydropower station proposed in SR01 (Fig. 5a) by two pumps working as turbines. It showed a great operation zone for different values of *DI* and *DTI* the *ERR* was above 0.85. Fig. 8b shows the power consumption ratio (*PCR*) of the PS01 pumping system. The plot established the optimization of the photovoltaic needs was excellent, since for any *DI* and *DTI* the used power was above 0.96 compared to the maximum installed power. Analysing this figure, the ratio was above

**Table 1**
Set of proposal alternatives to be evaluated.

| Id | Alternative | PV power (MW) | Volume DP01 + DP02 (hm$^3$) | Volume DP07 + DP04 (hm$^3$) | Volume DP06 (hm$^3$) | $Q_{PS01}$ (m$^3$/s) | $Q_{PS02}$ (m$^3$/s) | $Q_{PS03}$ (m$^3$/s) | Is it feasible? |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 12.5 | 0.70 | 0.54 | 1.50 | 1.7 | 3 | 1.8 | Yes |
| 2 | 2a | 12.5 | 0.70 | 0.54 | 1.50 | 1.7 | 1.5 | 1.8 | Yes |
| 3 | 2b | 8.0 | 0.70 | 0.54 | 1.50 | 1.7 | 1.5 | 1.8 | Yes |
| 4 | 3a | 12.5 | 0.70 | 0.54 | 1.50 | 1.7 | 3 | 1.8 | Yes |
| 5 | 3b | 15.0 | 0.70 | 0.54 | 1.50 | 1.7 | 3 | 1.8 | Yes |
| 6 | 3c | 17.5 | 0.70 | 0.54 | 1.50 | 1.7 | 3 | 1.8 | Yes |
| 7 | 4a | 12.5 | 0.35 | 0.54 | 1.50 | 1.7 | 3 | 1.8 | Yes |
| 8 | 4b | 12.5 | 0.35 | 0.54 | 1.50 | 2.5 | 3 | 1.8 | Yes |
| 9 | 4c | 20.0 | 0.35 | 0.54 | 1.50 | 2.5 | 3 | 1.8 | Yes |
| 10 | 5a | 12.5 | 0.35 | 0.54 | 1.50 | 1.7 | 3 | 1.8 | No |
| 11 | 5b | 12.5 | 0.35 | 0.54 | 1.50 | 2.5 | 3 | 1.8 | No |
| 12 | 5c | 20.0 | 0.70 | 0.54 | 1.50 | 2.5 | 3 | 1.8 | No |
| 13 | 6a | 12.5 | 0.70 | 0.54 | 0.75 | 1.7 | 3 | 1.8 | Yes |
| 14 | 6b | 12.5 | 0.70 | 0.54 | 0.15 | 1.7 | 3 | 1.8 | Yes |

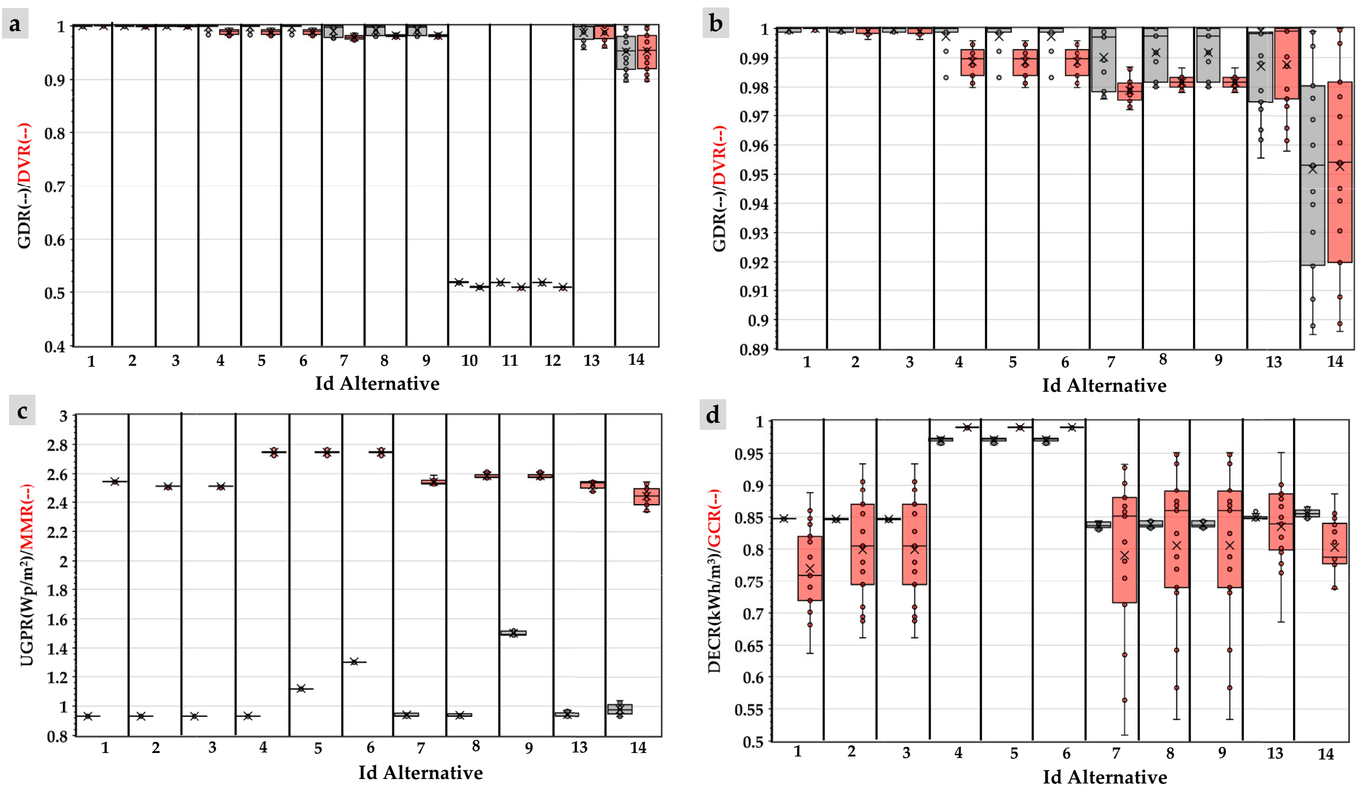



**Fig. 6.** Evaluation of technical indicators. (a) *GDR* and *DVR* for each Id; (b) *GDR* and *DVR* for feasible Id; (c) *UPGR* and *MMR* for different feasible Id; (d) *DECR* and *GCR* for feasible Id.

0.99 in the lower diagonal part.

Fig. 8c evaluates the *GDR* in all irrigation communities. The values of this indicator were above 0.95 when *DTI* was lower than 1.5. This figure shows how the entities receiving these volumes must undertake new modernisation and design plans to improve their regulatory capacities so that they can absorb the transfer of demands that guarantee zero discharge. Since distribution cannot be guaranteed by the regulation capacity of these entities, not by the strategy designed.

Fig. 8d is the key figure of the strategy. This figure shows the capacity to ensure zero discharge (*DVR*) of the established strategy. It can be seen that for any *DI* and *DTI*, the *DVR* was >0.99, except for specific moments of *DI* equal to 1, which in the winter months would lead to spills if the entities could not regulate. This is unlikely since all of them, to a greater or lesser extent, have this capacity. This figure justifies the success of the strategy proposed in this research. Fig. 8e and f show the capacity ratio for the different reservoirs, which established high values in all cases. When the global capacity ratio *(GCR)* was analysed (Fig. 8f), the majority area for each *DI* and *DTI* was above 0.85.

Table 2 shows the analysis of the different economic, social and environmental indicators that allow the study of the other alternatives. Although the analysis of the financial and social indicators is necessary to determine which alternative is the most viable from an environmental point of view, in this case, the analysis of the technical indicators and above all the zero-discharge indicator (*DVR*) is essential since the strategy must give greater weight to those that guarantee zero-discharge (*DVR = 1*) in all possible scenarios depending on the demand and demand transfer index of the same.

Although the table shows the detailed analysis of all the indicators set out in Block III, the last three rows deal with a summary of the Minimum *B/C Ratio* value that establishes a direct assessment of the strategy without considering the employment multiplier effect (*EME*) and the effect of renewable energy. All the evaluated feasible alternatives (Id) show values above 1 (value considered as feasible) except for alternative Id3 [45]. Id13 shows the best results with a value of 1.68, getting average values of *DVR* equal 0.91, equivalent to an annual discharge to sea of 0.21 $hm^3$ per year as a function of the analysed scenario. Against, alternative Id1 guaranteed zero discharge (DVR = 1) with a minimum *B/C* value of 1.64 similar to Id13. A similar trend was observed when the '*B/C without CEE*' ratio was evaluated without considering the *CEE* index but considering the *EME* index. All alternatives showed values between 2.69 (Id6) and 3.74 (Id14), except Id6 and Id9 which established values equal to 2.69 and 2.44, respectively. When the *B/C Global* indicator was evaluated, values between 9.42 and 12.39 were crucial the making decisions in the *DVR* and *GDR* since the main goal of the strategy is to guarantee zero-discharge and the introduction of the new water resources in the different irrigation communities, being able to distribute between different irrigation reservoirs. *B/C Global* showed a high value compared with other hydraulic systems evaluated in Spain. These hydraulic systems showed *B/C* around 4.1 [45]. Table 2 shows values, which improved satisfactory published indicators, improved employment by around 1.8 % and 3.7 % in the agricultural sector and indirect activities [50]. The reduction of nitrogen in water bodies was 23.3 %. This value was aligned with the proposed value by [61]. This contributes to reducing the use of fertilisers in the crops since the water contains elements involved in plant growth [62] and the improvement of the water resources for irrigated areas, showing above €150 million, similar as [30]. The proposal showed a ratio of around -0.56 kg $kgCO2eq/m^3$ compared with [63], who presented values around +2.08 $kgCO2eq/m^3$. This strategy displayed negative values because the system used a renewable hybrid system and it did not generate CO2 compared to grid consumption, which is shown around 40 % of non-renewable resources [41]. However, this ratio depends on the topology of the water systems, mainly the length of pipes, as well as the height of the irritation points. The increase of productivity is around 0.59 €/$m^3$ compared to 0.12€/$m^3$ reached by [46].

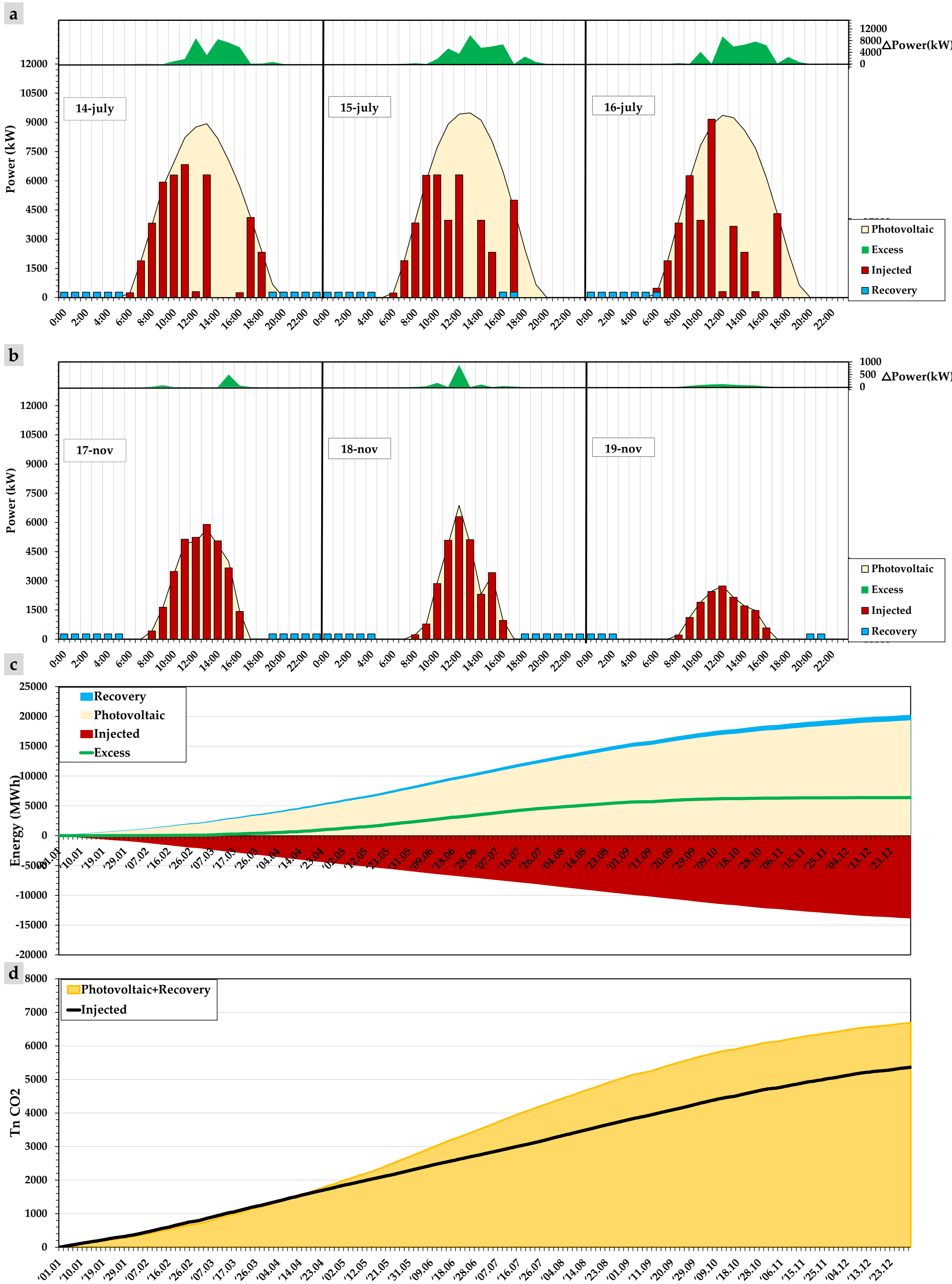



**Fig. 7.** Example of PV-micro hydropower system: (a) Example of daily generated and injected in summer; (b) Example of daily generated and injected in winter; (c) Global balance; (d) Balance of CO2 emissions.

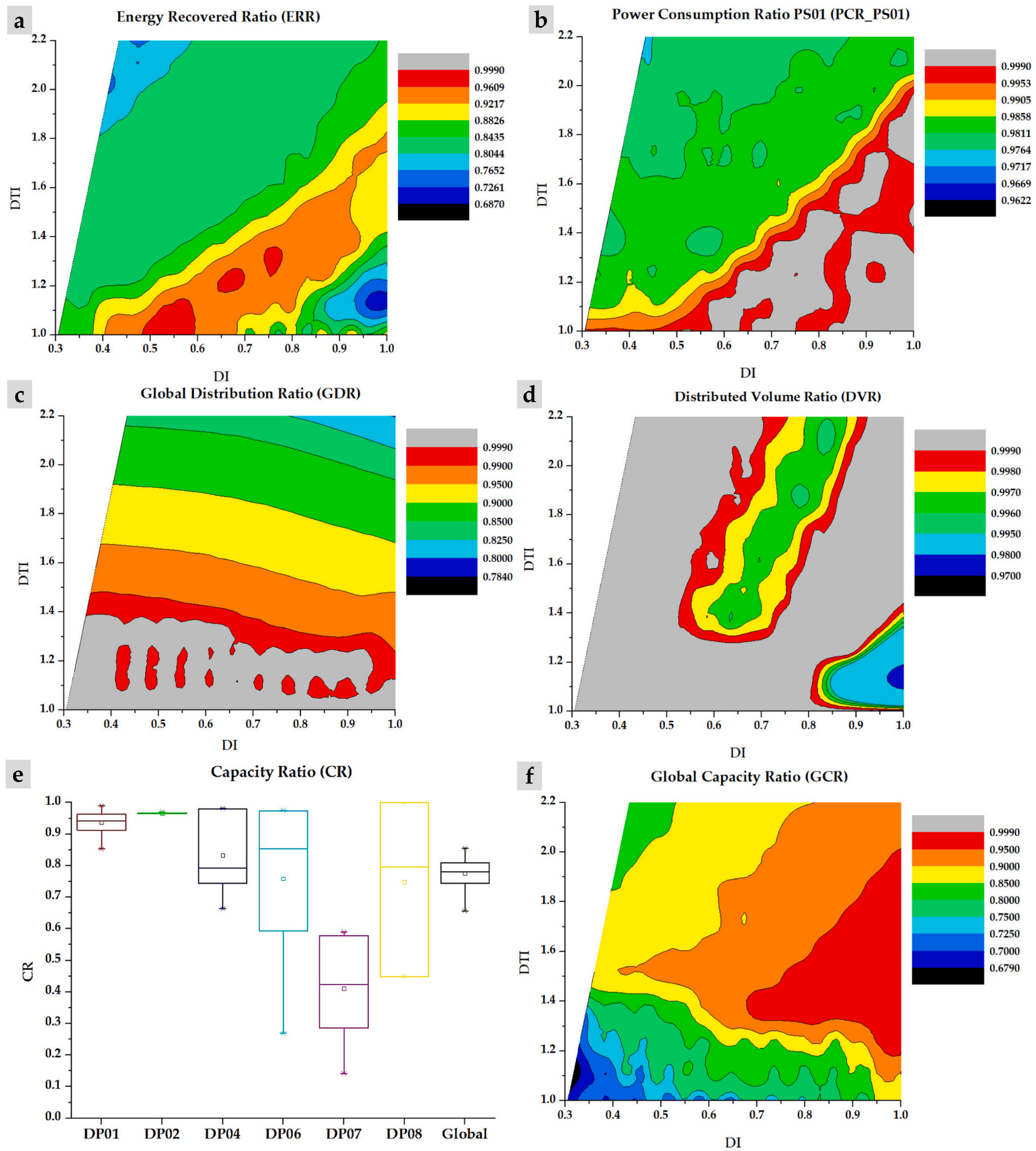



**Fig. 8.** Optimized procedure global balance of the best solution as a function of *DI* and *DTI*. (a) *ERR*; (b) *PCR*; (c) *GDR*; (d) *DVR*; (e) *CR* for each reservoir; (f) *GCR*.

## 4. Conclusions

Irrigation systems have revolutionized agricultural productivity by influencing hydraulic system design, energy use, and sustainability. Recent research presents a strategy aimed at ensuring that reclaimed wastewater treatment plants (WWTPs) do not discharge into the sea. This approach utilizes an optimized procedure to enhance water distribution for communities, reduce sea discharge, and lower energy consumption. The strategy integrates floating photovoltaic systems on reservoirs and micro hydropower with pumped storage to maintain water distribution.

Addressing green strategies for resource reuse, especially water, is crucial for improving SDG6 and preventing watercourse and sea pollution from wastewater. Direct wastewater discharges contribute to Mediterranean eutrophication, with rising phosphorus inputs posing a future risk. Tertiary treatment and phosphorus management, though

**Table 2**
Economic and social indicators.

| Indicator | | Alternative Id | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 13 | 14 |
| EAC | **$10^6$ € /year** | 13.16 | 13.22 | 9.67 | 13.26 | 15.23 | 17.20 | 12.93 | 12.96 | 18.87 | 12.55 | 11.99 |
| BIP | | 8.18 | 4.78 | 2.83 | 7.99 | 7.99 | 7.99 | 7.82 | 7.87 | 7.87 | 7.97 | 7.37 |
| DRB | | 0.92 | 0.54 | 0.32 | 0.90 | 0.90 | 0.90 | 0.88 | 0.89 | 0.89 | 0.90 | 0.83 |
| BIE | | 6.72 | 3.93 | 2.32 | 6.57 | 6.57 | 6.57 | 6.43 | 6.47 | 6.47 | 6.55 | 6.06 |
| IGB | | 4.02 | 3.01 | 2.43 | 3.96 | 3.96 | 3.96 | 3.91 | 3.93 | 3.93 | 3.96 | 3.78 |
| WBIB | | 1.34 | 0.67 | 0.28 | 1.30 | 1.30 | 1.30 | 1.27 | 1.28 | 1.28 | 1.30 | 1.18 |
| NRI | | 0.14 | 0.14 | 0.14 | 0.14 | 0.14 | 0.14 | 0.14 | 0.14 | 0.14 | 0.14 | 0.14 |
| CEE | | 128.85 | 128.85 | 82.46 | 128.85 | 154.62 | 180.39 | 128.85 | 128.85 | 206.16 | 128.85 | 128.85 |
| LRI | | 0.28 | 0.28 | 0.28 | 0.28 | 0.28 | 0.28 | 0.28 | 0.28 | 0.28 | 0.28 | 0.28 |
| EME | | 25.22 | 25.22 | 25.22 | 25.22 | 25.22 | 25.22 | 25.22 | 25.22 | 25.22 | 25.22 | 25.22 |
| Minimum B/C | | 1.64 | 1.01 | 0.89 | 1.59 | 1.39 | 1.23 | 1.60 | 1.61 | 1.11 | 1.68 | 1.64 |
| B/C without CEE | | 3.56 | 2.92 | 3.50 | 3.50 | 3.04 | 2.69 | 3.55 | 3.56 | 2.44 | 3.69 | 3.74 |
| B/C Global | | 11.43 | 10.76 | 9.42 | 11.31 | 11.54 | 11.71 | 11.57 | 11.55 | 12.03 | 11.94 | 12.39 |

costly, can help. Water management must prioritize sustainable alternatives to direct discharge and marine outfalls, addressing pollution from biological contaminants and microplastics. Effective solutions require understanding input states, energy use in wastewater treatment, and evaluating water-reuse projects from multiple perspectives.

The findings suggest that this method can be applied broadly to any irrigation system with WWTPs, potentially preventing coastal degradation while supplying 24.1 % of the irrigable land near Alicante. Within the zero discharge process, the limitations may lie not in the optimization processes or application technologies but in the problems of space to house the water treatment infrastructures, regulating ponds and artificial wetlands, a consequence of which is the lack of a water treatment system. This can be applied to any case study in technical terms. However, there may be cases where economic viability is compromised or where the lack of irrigation users cannot act as sinks (this was defined in Block I).

Future research will concentrate on refining techniques for hydraulic systems to address water deficits exacerbated by climate change. Additionally, it will explore optimizing hybrid renewable energy systems and new advances in green energies to ensure hydraulic models remain viable from social, economic, technical, and environmental perspectives. This includes analysing the mix of water from different sources, assessing sensitivity to water quality, and investigating treatment processes that affect water quality, all of which are crucial for effective water management in changing environmental conditions.

## Fundings

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## CRediT authorship contribution statement

**Modesto Pérez-Sánchez:** Writing – original draft, Methodology, Funding acquisition, Formal analysis, Conceptualization. **Francisco-Javier Sánchez-Romero:** Methodology, Conceptualization. **Francisco A. Zapata:** Investigation, Conceptualization. **Helena M. Ramos:** Writing – original draft, Supervision.

## Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Modesto Pérez-Sánchez reports financial support and article publishing charges were provided by Polytechnic University of Valencia. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jwpe.2024.106351.

## Data availability

Data will be made available on request.

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