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Is it possible to develop a green management strategy applied to water systems in isolated cities? An optimized case study in the Bahamas

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ABSTRACT

The inclusion of new strategies is crucial to achieve the different targets of the sustainable development goals for the guarantee of supply in the different cities and reduction the consumption of non-renewable resources. The development of these strategies implies the improvement of the sustainability indicators and green rating systems of the city. This research proposes a decarbonisation strategy, which includes different optimization procedures based on a self-calibration process according to recorded flow values over time. These stages are integrated into one tool to define the best making decision in the management of the supply system, analysing whether self-consumption of energy is feasible. It was applied on the Bahamas. The application of the strategy enabled the decrease of the annual consumption of energy equal to 32%. The self-consumption could represent 30% of the consumed energy of the pump station. The making decision to define the best operation strategy, establishing a Levelized Cost of Energy around 0.12 €/kWh when the feasibility of using photovoltaic systems combined with micro hydropower was done. It implies the reduction of 40% of the tCO2 emission, getting a cost of carbon abatement values around 400 €/tCO2 for different discount rates and scenarios.

1. Introduction

The consequences caused by climate change are generating that the policies of the managers are focused on improving sustainability since climate change presents one of the main threats to the environment, clean power production and reduction of energy consumption are among the primary guidelines used to face this current reality (Venkatesh, Chan & Brattebø, 2014). Water supply systems consume considerable energy (Sowby, 2018). One of the most critical approaches to improving energy use and production management focuses on water utilities (Proctor, Tabatabaie & Murthy, 2021).

The management of the cities is being supervised to reach new sustainable management for smart cities. These new strategies must contemplate solutions for metropolitan life and the ecological environment (Nagarajan, Deverajan, Chatterjee, Alnumay & Muthukumaran, 2022). The water sector has a high significance in the sustainable development in the cities. The different stages (i.e., collection, purification, distribution, and wastewater treatment) require high values of energy consumption. (Chini & Stillwell, 2018). It implies the development of strategies, which could be used by water managers. These strategies are developed in all phases and the sustainable management of resource capture is crucial.

Water scarcity caused the need to develop new hydro-economic models to enhance the sustainability of urban groundwater (Arasteh & Farjami, 2021) and the improvement of the desalination techniques, which guarantee the supply of cities (Suwaileh, Pathak, Shon & Hilal, 2020). In this line, the behavior of aquifers is a very important role (Roshani & Hamidi, 2022) and different models to predict their oscillations were reviewed by Tao et al. (2022). Once the water is collected, society developed innovative techniques for water purification, increasing the sustainability of water treatment techniques (Cui et al., 2021).

The water distribution does not go unnoticed in improving the sustainability of cities, proposing new trends and regulations that increase their resilience (Luthy, Asce, Wolfand & Bradshaw, 2020). Several methodologies were proposed by different researchers from a sustainable point of view, to preserve public health and social growth (Shahmirnoori, Saadatpour & Rasekh, 2022). The sustainability in the water

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distribution systems is mainly focused on (i) management of pressure by optimization proposals to reduce leakage (Feng, Zhang, Rad & Yu, 2021), (ii) minimizing energy use when pumped systems are used by different optimization procedures (both mathematical and heuristic techniques (Vakilifard, Anda, Bahri & Ho, 2018)) and (iii) the proposal of smart self-energy systems, which can take advantage of the operation constrains of the water system to generate energy by hybrid systems (e.g., solar, hydro, wind turbines, among others) (Cao et al., 2022).

At the final step of the water use cycle, green strategies applied to the wastewater process were reviewed from political, economic, technological and environmental points of view (Sgroi, Vagliasindi & Roccaro, 2018). A multi-objective optimization model for a sustainable waste management system was proposed by Rabbani, Mokarrari and Akbarian-saravi (2021), in which, the reduction of energy consumption is the main objective of the different proposed techniques for the increase of efficiency and energy savings (Capodaglio & Olsson, 2019).

This symbiosis of water and energy is also shown in the green rating systems (Nguyen & Altan, 2011). Water and energy have a high weight, representing more than 50% with respect to the rest of the criteria and factors (Alwisy, BuHamdan & Gül, 2018). This rating defines a set of standards to mitigate the negative environmental impact of facilities, encouraging the adoption of greener technologies (Nguyen & Altan, 2011). These rating systems help to define the different requirements (i.e., mechanical and electrical) and align them to use renewable energy systems (Alwisy et al., 2018).

These green ratings as well as the use of sustainable indicators (Maurya, Singh, Ohri & Singh, 2020) caused the scientific community to focus its attention on the study of obtaining clean energy or recovered energy in distribution systems. In constraint, implementing policies, which regulate energy consumption for water utilities can reduce energy use by up to 30% compared to unregulated utilities (García Morillo, McNabola, Camacho, Montesinos & Rodríguez Díaz, 2018). An ideal development pathway allows water managers to derive an appropriate balance between environmental, economic, and societal interests. It requires a multi-stakeholder approach involving all interest groups in the decision-making process is required (Tekken & Kropp, 2015).

Water management in cities is constrained by stricter water-quality standards, increasing the demand for water and the requirement to adapt to climate change while reducing GHG emissions (Rothausen & Conway, 2011). The increase of efficiency in the production, transformation and utilization of energy requires improvements in the operation and design of current technologies. Furthermore, these technologies should reduce the use of non-renewable sources (Liu, Tait, Schellart, Mayfield & Boxall, 2020). The different challenges of the last years such as the increase in energy and water demand, variations in fuel costs, and constant concerns about climate change caused the different regulatory entities to focus their attention on increasingly efficient sources of energy production (Delina, 2012).

The main objective is that the different city service managers can develop more efficient energy systems (Pardo, Manzano, Cabrera & García-Serra, 2013). These interactions should be recognized as a win-win relationship between managers (WHEATER, 2000). One of the solutions to increase the green rating systems is the inclusion of hybrid power generation systems, as well as the use of renewable sources of energy (Ribeiro, Saavedra, Lima, de Matos & Bonan, 2012). These sources allow systems to operate at an efficient operating point, as well as allow for flexibility in system expansion to power future sustainable cities (Blum, Sryantoro Wakeling & Schmidt, 2013).

Over the past few decades, the facilities that offer tourist services have grown, which is equivalent to a greater consumption of resources such as water and energy (Cirer-Costa, 2012). When the water system is isolated, it occurs on islands or remote areas mainly, the use of renewable energy technologies is crucial to get green energy sources, which are pollution-free, available at free of production cost and easily accessible even in remote areas (Shyni & Ramadevi, 2022).

Places located in remote areas, which are non-electrified and/or isolated, are opting for the installation of green renewable systems because it makes it easier to obtain energy for the water supply in these areas (Kim, Park, Kwon, Ohm & Chang, 2014; Lee et al., 2017; Mekhilef, Saidur & Safari, 2011; Mundo-Hernández, De Celis Alonso, Hernández-Álvarez & De Celis-Carrillo, 2014). (Elkadeem, Wang, Sharshir & Atia, 2019) showed the modernization of agriculture and irrigation area in Dongola, Sudan, reaching Levelized Cost of Energy (LCOE) around 0.35 €/kWh. (Blum et al., 2013) developed a deep review and analysis of the LCOE values when Indonesian villages are implemented with hybrid systems (photovoltaic, microhydropower and/or other green energies), being compared with conventional diesel solution. These LCOE values were between 0.2 and 0.8 €/kWh depending on localization and the adopted solution. Similar analyses were done in the Amazonian region, in which the LCOE values oscillated between 0.25 and 1 €/kWh depending on the green energy system proposed by the managers (Sánchez, Torres & Kalid, 2015). (Timilsina, 2021) calculated more than 4000 LCOE values for 11 different technologies around the world, showing the LCOE values in Table 1

The practical implication of synergies is improved financial and environmental outcomes of resource efficiency investments (Becken & lee McLennan, 2017). Different studies showed the installation of photovoltaic panels with battery combined with other wind-battery plants tends to be the best option for clean energy production (Biswas, Bryce & Diesendorf, 2001; Dorji, Urmee & Jennings, 2012). The use of solar batteries, wind batteries, or different hybrid clean energy sources for pumping stations is the alternative that is gaining more significance (Najafi Ashtiani, Toopshekan, Razi Astaraei, Yousefi & Maleki, 2020). These alternatives guarantee the amount of energy needed for water distribution systems and have significantly lower water volume requirements than other emerging technologies (Tarroja et al., 2014).

Studies showed the use of photovoltaic panels in isolated communities in different parts of the world, there is a reduction in the use of fossil fuels by up to 67% (Millinger, Mårlind & Ahlgren, 2012). It shows new sustainable alternatives to provide energy for pumping systems, reducing GHG emissions in a critical proportion (Caniglia, Frank, Kerner & Mix, 2016). The electrification and coupling of transport and residential heating could reduce CO2 emissions by around 25% (Vujanović, Wang, Mohsen, Duić & Yan, 2021).

The water systems are not far away from these new trends. The water managers need to incorporate the use of hybrid systems to reduce the non-renewable energy consumption, as well as their carbon footprint (Javed, Zhong, Ma, Song & Ahmed, 2020). Water research groups, who searched the improvement of these parameters, published different approaches. (Guezgouz et al., 2019) analyzed the use of hybrid storage also reduces the curtailment of renewable generation by multiobjective programming, reaching LCOE values around 1.462 €/kWh. A novel meta-heuristic algorithm called the artificial sheep algorithm was applied in pumped water system optimization (Xu, Li, Wang, Zhang & Peng, 2018). In these systems, (Javed et al., 2020) proposed an

Table 1
Range of the LCOE values.

Energy System	LCOE Values (€/kWh)		
	Minimum	Median	Maximum
PV	0.024	0.046	0.115
Concentrated solar	0.103	0.117	0.145
Wind Onshore	0.034	0.047	0.108
Wind Offshore	0.065	0.118	0.161
Gas Combine cycle	0.053	0.061	0.066
Gas turbine	0.074	0.085	0.088
Geothermal	0.025	0.051	0.105
Hydro	0.015	0.044	0.115
Coal	0.041	0.068	0.087
Nuclear	0.041	0.075	0.125
Biomass	0.020	0.074	0.174

operating strategy to integrate pumps as turbines in water supply systems, improving the use of the regulation by around 20%.

The background shown in the last paragraphs emphasized the use of green renewable systems applied in storage systems and/or known demand. The main goal of this research is to propose a methodology to improve the management of supply systems in cities including their green irrigation areas of gardens, mainly when the supply is isolated (e.g., in remote areas or islands). The strategy incorporates a preview calibration procedure based on the registered flow to adjust the consumption pattern to real over time. It integrates the use of different hybrid systems and it joined two simulated annealing procedures to choose the best recovery systems. In addition, the proposed methodology used a Newton-Raphson optimization method to adjust the pumping stations, achieving the minimization of pumped energy in the supply system. The strategy closes using a making decision procedure to choose the best management option to improve sustainability indicators in the management of the city.

The novelty of this research is the integration in the same modeling tool, optimization methods and making-decision of the management to assimilate hybrid systems and maximize the good practices in water distribution systems. This will be done by combining three important branches of sustainability: (i) technical (ensuring pressure and flow demand), (ii) economical (Levelized Cost Of Energy values), and (iii) environmental (Cost of Carbon Abatement and others sustainable indicators). All of them very important aspects of the management of the city and its facilities for citizens.

2. Materials and methods

The proposal of this optimized strategy to develop green hydraulic

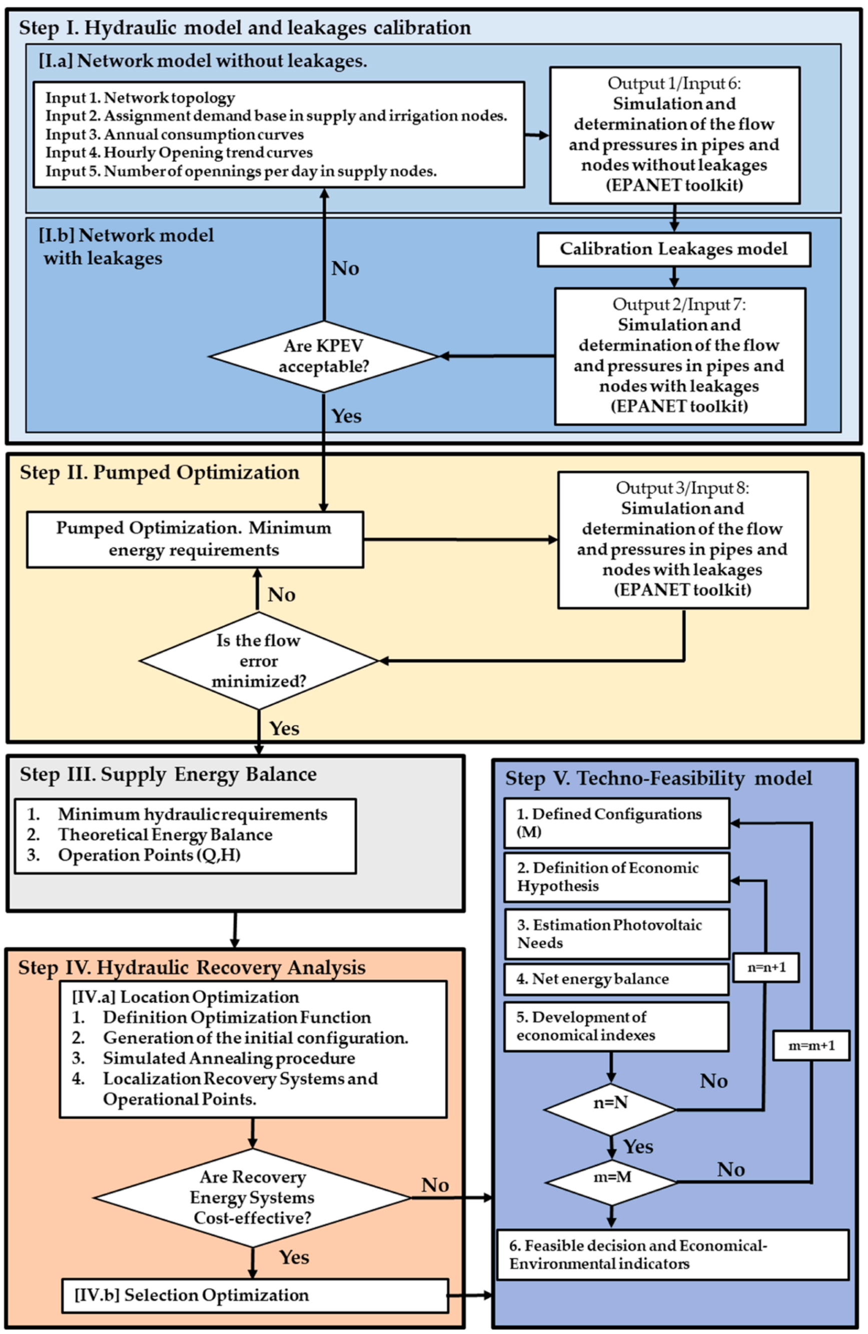

Fig. 1. Proposal of the optimization strategy.

management is divided into five different steps (Fig. 1): (I) Hydraulic model and leakages calibration, (II) Pumped optimization, (III) Supply Energy Balance, (IV) Hydraulic Recovery Analysis, and (V) Techno-Feasibility hybrid model. Each step defines different substeps or optimization procedures, which allow managers to obtain output results. These values are used as inputs in other following steps.

Hydraulic model and leakages calibration (Step I) is based on developing a calibrated hydraulic model of the system to develop the different following steps. It is composed of two sub-stages. The first substep (I.a) is focused on developing the digitalization of the model. This first model is focused on different inputs. Input 1 develops the network topology, considering the GIS information of the system in terms of pipes, joints, length, heights, roughness and materials. Input 2 is focused on the assignment of the demand base in the supply and irrigation nodes. This second input used the recording of the different counter of the consumption points both irrigation and supply. Input 3 defines the annual consumption curves, which are established using the different flowmeters of the network compared with the main flowmeter of the system. Input 4 is focused on developing the hourly opening trend curves. These curves are based on historic recordings, allowing managers to develop them. Finally, Input 5 establishes the number of openings in consumption nodes. This parameter is established by the strategy to adjust the observed and simulated model.

The development of this step I.a enables the getting of the simulation and determination of the flow and pressures in pipes and nodes without leakages. It is developed using the Epanet toolkit (Rossman, 1999). Once, the model is developed, the strategy includes a calibration procedure, which enables the estimation of the leakages in the model and their simulation to know the real values of flow and pressure in the system (Output 2). This output value is the input, which enables the pumped optimization in step II. The calibration stage is included on substep I.b. Leak calibration is using the proposed strategy defined by C. A. M. Ávila, Sánchez-Romero, López-Jiménez and Pérez-Sánchez (2021). The leakage in each line is evaluated by the following equation:

$$q_{ij} = K_i\left(\overline{P_{ij}}\right)^N \tag{1}$$

where q_{ij} is the leakage flow for element i for interval j; $\overline{P_{ij}}$ is the average pressure value in line i for interval j; N is the leakage exponent and K_i is the global emitter coefficient for line i. This coefficient is calculated by iterative procedure and it is constant in all annual simulations. The following expression is used:

$$K_i = \frac{V_i}{\sum_j \left(\overline{P_{ij}}\right)^N \cdot \Delta t} \tag{2}$$

where V_i is the leakage volume for line i in m^3, assuming that the total leakage volume is distributed between all lines of the network and proportional to the line length.

The calibration procedure is iterative, comparing simulated and recorded values and calculating key performance error values (KPEVs). These KPEVs are Nash-Sutcliffe coefficient (E), which can oscillate between 0 and 1; Root Relative Squared Error (RRSE), which shows values greater o equal to zero and PBIAS value, which can take values greater than zero. Also, the calibration method analysed the BIAS applied to circulation flow between simulated and observed values. The expressions for the different KPVEs are defined in Table 2

Fig. 2 shows the satisfactory scale degree of these KPEVs according to Moriasi et al. (2007) and (Hossain, Hewa, Chow & Cook, 2021).

When the KPEVs are acceptable and stable according to Fig. 2, the strategy continues to Step II. This step is applied when the water distribution network contains a pumped system.

The head and efficiency curves for the pump machine are defined by the following equations:

Table 2
Definition of the KPVE expression.

KPEV	Expression	Variable
E	$1 - \frac{\sum_{i=1}^{N}[O_i - S_i]^2}{\sum_{i=1}^{N}[O_i - \overline{O_i}]^2}$	O_i is the observed value in each interval $\overline{O_i}$ is the average of the observed values S_i is the simulated value in each interval
RRSE	$\sqrt{\frac{\sum_{i=1}^{N}[O_i - S_i]^2}{\sum_{i=1}^{N}[O_i - \overline{O_i}]^2}}$	
PBIAS (%)	$\frac{\sum_{i=1}^{N}(O_i - S_i)}{\sum_{i=1}^{N} O_i}\cdot 100$	
BIAS (l/s)	$\frac{\sum_{i=1}^{N}(O_i - S_i)}{N}$.	

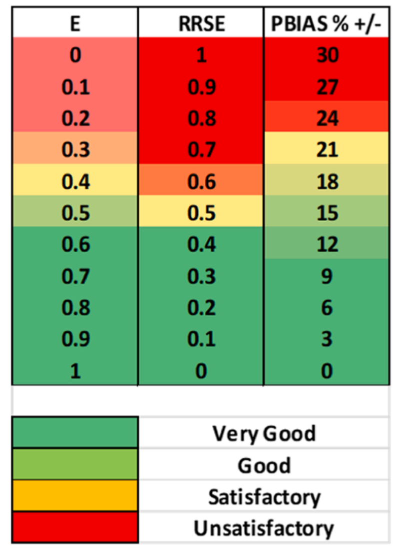

Fig. 2. color calibration scale as a function of the KPEVs.

$$H = \alpha^2\left(A + B\frac{Q}{\alpha} + C\frac{Q^2}{\alpha^2}\right) \tag{3}$$

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

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 η is the efficiency of the machine. The rest of the coefficients $(A, B, C,\ E_4, E_3, E_2, E_1\ and\ E_0)$ define the characteristics curves provided by the manufacturers.

The step shown in Fig. 3 develops an iterative regulation strategy

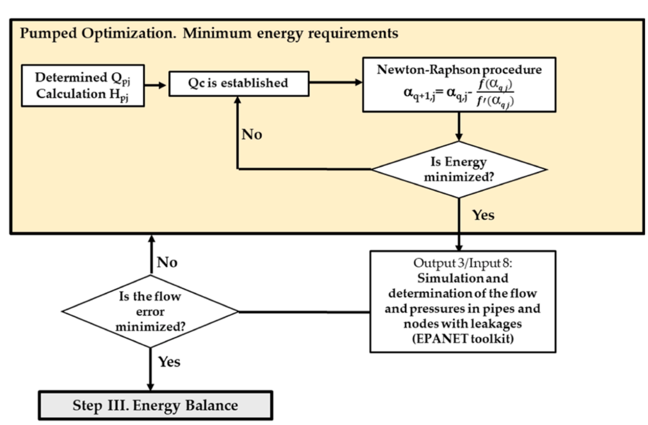

Fig. 3. Optimization procedure inside of Step II.

based on the Newton-Raphson optimization method (Tsakiris & Spiliotis, 2014), which defines the rotation speed of the pumping station according to the minimum requirements of flow and pressure. For each interval, the α value is calculated to optimize the pump operation points, establishing de best operation points of the pumping station (i.e., flow, head and efficiency and rotational variable speed, α), establishing a Q_c value, which is the flow rate between pumps, when in the system are two or more pumps.

The optimization procedure reaches the best operational points of the machine in terms of energy requirements for each interval j and iteration, but the changes in the values of α imply changes in the system pressure, modifying the values of existing leaks and flows. For each iteration, the model calculates: Q_{pj} is the pumped flow for interval j (m^3/s) and H_{pj} is the required pumped head for interval j (m w.c.). It is defined according to the following expression:

$$H_{pj} = max\left(P_{ij,min} - P_{ij}\right) \tag{4}$$

where $P_{ij,min}$ is the minimum pressure of service required for interval j (m w.c.), P_{ij} is the pressure in the node for interval j (m w.c.). Each optimization procedure established the error between simulated flow values between iterations, calculating the values for KPEVs, minimizing it as a function of each scenario. Once the error is minimized, the strategy established this regulation and it continues forward in step III, getting a new Epanet model simulation, which includes the pumping station as well as the rule controls to define the regulation and operation of them (Output 3/Input 8).

This step allows managers to elaborate a technical audit of their management in the pumped station, enabling the implementation of new operating rules to minimize the consumed energy.

The third step is focused on developing the energy balance of the system, considering the minimum energy requirements to satisfy the demand. It enables the estimation of the available energy to be recovered, discretizing the operation points of the potential recovery system. This energy balance is developed using the calibrated model for the pumped system, which is obtained in step II. This audit of the energy in the system is developed by the following expressions, which are summarized in Table 3: where i and j define the studied element (lines or consumption nodes) and interval time respectively; q is the number of time intervals considered for discretizing a year; Q_{ij} is the flow over time in the element i for interval j (m^3/s); z_i is the head level of the analyzed point (m); z_0 is the level of the free water surface of the reservoir (m); Δt is the time interval; P_{ij} is the service pressure in the node for interval j when there is consumption (m w.c.); $P_{min\ ij}$ is the minimum pressure to guarantee the most unfavorable node for interval j (m w.c.); $P_{min\ C}$ is the minimum pressure of service; H_{ij} is the head in the studied point for interval j (m w.c.), obtained as: $H_{ij} = P_{ij} - \max(P_{\min ij}; P_{\min C})$ and Q_{p_j} is the pumped flow in for each time (m^3/s).

The development of energy balance enables the definition of the theoretical recoverable energy as well as the operational points in each line or consumption node. These operation points are used in the fourth step of the strategy. Step IV is focused on the development of optimization of both location and selection recovery systems in the water system.

Table 3
Definition of the energy expressions in a water distribution system.

Energy	*Calculation expression*	
Total Energy (E_{Ti})	$E_{Ti}(kWh) = \sum_{j=1}^{j=q} \gamma\ Q_{ij}\ (z_0 - z_i)\ \Delta t$	(5)
Friction Energy (E_{FRi})	$E_{FRi}(kWh) = \sum_{j=1}^{j=q} \gamma\ Q_{ij}\ (z_0 - (z_i + P_{ij}))\ \Delta t$	(6)
Pumped Energy (E_{pi})	$E_{pi}(kWh) = \sum_{j=1}^{j=q} \gamma\ Q_{p_j}\ H_{p_j}\ \Delta t / \eta_{p_j}$	(7)
Theoretical Energy Necessary (E_{TNi})	$E_{TNi}(kWh) = \sum_{j=1}^{j=q} \gamma\ Q_{ij}\ P_{\min ij}\ \Delta t$	(8)
Energy required for consumption (E_{RIi})	$E_{RIi}(kWh) = \sum_{j=1}^{j=q} \gamma\ Q_{ij}\ P_{\min C}\ \Delta t$	(9)
Theoretical Available Energy (E_{TAi})	$E_{TAi}(kWh) = \sum_{j=1}^{j=q} \gamma\ Q_{ij}\ (P_{ij} - P_{\min C})\ \Delta t$	(10)
Theoretical Recoverable Energy (E_{TRi})	$E_{TRi}(kWh) = \sum_{j=1}^{j=q} \gamma\ Q_{ij}\ H_{ij}\ \Delta t$	(11)
Theoretical Unrecoverable Energy (E_{NTRi})	$E_{NTRi}(kWh) = E_{TAi} - E_{TRi}$	(12)

The location optimization, called IV.a in Fig. 1, is defined by five different substeps: (i) Definition Optimization Function; (ii) Generation of the initial configuration; (iii) Simulated Annealing procedure; (iv) Localization Recovery Systems and Operational Points.

The definition of the objective functions is based on: maximizing recovered energy, maximizing leakages reduction, minimizing the Levelized Cost of Energy (LCOE) and maximizing net present value (NPV).

The LCOE function only considers the initial investment and annual costs. Therefore, it does not depend on the energy price, when the LCOE value is applied in recovery systems. When the LCOE is estimated for pump stations, the use of external energy implies the need to consider the energy price. The LCOE function is defined by the following expression (Lugauer, Kainz & Gaderer, 2021):

$$LCOE = \frac{IC_0 + \sum_{i=1}^{i=T} \frac{AC_i + F_i}{(1+k)^i}}{\sum_{i=1}^{i=T} \frac{E_i}{(1+k)^i}} \tag{13}$$

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_i is the operation and maintenance costs in € for the year i; F_i is the fuel expenditures in €. F_i is only considered in pumped situations, when the LCOE is determined for recovery systems, F_i is equal to zero.; E_i is the annual recovered energy in kWh for the year i; T is the lifetime in years, considering 25 years since it coincides with the photovoltaic panels; k is the real discount rate using a sensitivity analysis between 0.01 and 0.1.

The Net Present Value (NPV) is defined by the following expression (Lim, Park & Park, 2007):

$$NPV = -IC_0 + \sum_{i=1}^{i=T} \frac{AI_i - AC_i}{(1+k)^i} + RI_T \tag{14}$$

where: AI_i is the annual income in the year i; k is the real discount rate; IC_o includes the initial investment for the implementation, installation and operation of the recovery systems ((Carravetta, Fecarotta, Sinagra & Tucciarelli, 2014; García, Novara & Mc Nabola, 2019)). AC_i consider the annual maintenance costs of the recovery systems according to Giudicianni et al. (2020). AI_i contemplate the annual incomes generated when the self-consumption benefits are considered, mainly the reduction of fuel consumption in diesel generator both water system and other uses, requiring diesel generation (Lal, Bhusan Dash & Akella, 2011). To analyze the NPV value, the optimization model considers the water savings relative to leakages reduction. The residual income (RI_T) establishes the sale of the different elements when they reach their ended lifetime.

Each objective function is analysed in the water system by the application of the simulated annealing algorithm. It defines the first configuration and the procedure is applied according to Pérez-Sánchez, Sánchez-Romero, López-Jiménez and Ramos (2018). The procedure gives as a solution the best location of the PAT systems. This step IV.a enables the feasibility of the use of PAT recovery systems in the analysed network. If there is no feasibility, the model continues to Step V, analysing the photovoltaic generation. If the feasibility is possible, the strategy should choose the best machine to define the recovery system as well as the regulation rules. These actions are developed in step IV.b. It uses a database machine incorporated into the programming software. The second substep establishes the different regulation strategy to be incorporated into the optimization strategy. The manager can define different variable operation strategies (VOS) as nominal rotational speed and other configurations, considering the variation of the rotational speed. The manager can select the best power head (BPH), best efficiency head (BEH) and best power flow (BPF) (C. A. M. Ávila, Sánchez-Romero, López-Jiménez & Pérez-Sánchez, 2021). The definition of both chosen machine and its regulation strategy establishes the first configuration. This is introduced in the other simulated annealing algorithm, which defines the best number of machines, flow regulation per machine and recovered head depending on the selected optimal strategy. The result of step IV.b enables the definition of the recovery system to be included in Step V, which develops the final decision support to establish the green hybrid renewable system.

Step V defines the optimization of the hybrid model when the use of a hydraulic recovery system is evaluated their feasibility. This step introduces the photovoltaic analysis to be introduced in the system management to reach zero energy consumption. Previously, the different configurations are established according to different possibilities. These configurations are configurations A and B. Both configurations considered the pumped system, and analysed the feasibility of the recovery systems, using photovoltaic systems. For configuration B, batteries are installed and the system runs completely isolated. For configuration A there are no installed batteries and the system remains connected.

The second substep of this feasible optimization establishes for each configuration different economic hypotheses. The economic analysis defines two possible prices (current and future), although the methodology could include more values. The strategy defines four different real discount rates (0.01, 0.04, 0.07 and 0.1). The analyzed model is twenty-five years because it is the PV system. The optimization considers that the properties of the battery do not change over time and are not affected by external factors such as temperature (Al-Karaghouli & Kazmerski, 2010). The lost capacity is considered by a greater factor equal to 1.25 inside of the feasible analysis. The batteries are changed in the half of the lifetime of the PV system.

The third link of the stage is focused on the estimation of the photovoltaic needs as well as the estimation of its generation, according to the calculus of the hourly irradiance along the year. The strategy develops an improvement of the analytical model proposed by Picazo, Juárez and García-Márquez (2018). The model defines the latitude and declination angles, day of the year and the rest of the solar parameters over time. The strategy incorporates the different equations, which were defined by Picazo et al. (2018). The knowledge of features of the photovoltaic system, the hourly irradiance and cell temperature joined to geographic parameters enable the definition of the unit hourly used by area, in addition to the optimum tilt angle. These parameters establish the unit value to develop the techno-feasible model as a function of the used area including other renewable systems. This energy analysis is developed in the fourth substeps. Once the energy analysis has been developed, the economic balance considers different investment costs. These are grouped into different groups: Investment Cost and Annual Cost.

The Investment Cost (IC) is defined by the following expression:

$$IC = IC_{CD} + IC_{OPC} + IC_{Civil} + IC_{PATs} + IC_{CV} + IC_{PRV} + IC_{Pipe} + IC_{FM} + IC_{PV} + IC_{Soil} + IC_{Battery} \quad (15)$$

where IC_{CD} is the investment cost relative to the control device. Electric and Electronic devices for the control of the system. It is defined by 0.24·IC according to García et al. (2019); IC_{OPC} the investment cost relative to Other Project Cost including Engineering Taxes. It is equal to 0.19·IC (García et al., 2019); IC_{Civil} is the civil works, defined as 1020 €/kW (Bousquet et al., 2017); IC_{PATs} the investment cost relative to hydraulic motor/generator cost, defined as 350 €/kW (Carravetta, Del Giudice, Fecarotta & Ramos, 2013); IC_{CV} the investment cost relative to control valves in €. It is estimated as $0.028D^{1.86}$ (D is the diameter in mm); IC_{PRV} the investment cost relative to pressure reduction valves. It is estimated as $1.34D^{1.32}$ (D is the diameter in mm); IC_{pipe} the investment cost relative to pipes in €. It is estimated as $0.218D^{1.053}$ (D is the diameter in mm); IC_{FM} the investment cost relative to flowmeter. It is estimated as $0.195D^{1.59}$ (D is the diameter in mm); IC_{CV}, IC_{PRV}, IC_{pipe}, IC_{FM} are valued considered by GrupoTragsa (2021); IC_{PV} is the investment cost of the solar panels and installation. It is estimated as 700 €/kW (PVPS, 2019); IC_{Soil} is the investment cost relative to purchase of land in €. It is estimated in 5000 €/ha according to the selling price of the island; $IC_{Battery}$ is the investment cost of the batteries. It is considered as 518.8 €/kWh according to U. S. E. I. Administration (2021).

The Annual Cost (AC) is defined by the following expression:

$$AC = AC_{OMEX} + AC_{EXP} + CO_2C \quad (16)$$

where AC_{OMEX} is the operational and maintenance cost in €. It is considered 0.1IC for injected and recovery systems according to Giudicianni et al. (2020) and 15 €/kW·year for photovoltaic systems (Talavera, Muñoz-Cerón, Ferrer-Rodríguez & Pérez-Higueras, 2019); AC_{EXP} is the economic expenditure on non-renewable energy. The considered current energy price is 0.33 €/kWh and the future price is 0.66 €/kWh. These prices are defined based on (Lab, 2015) . CO_2C is the cost/profit in € for the environmental profit; C_T is the carbon tax. It is equal to 0.1162 €/kg CO_2 according to Picazo et al. (2018) (Bousquet et al., 2017). This C_T considers an annual increase equal to 3% according to Rausch and Yonezawa (2018). The CO_2 emissions due to the use of diesel generators are defined by the following expression (Jakhrani, Rigit, Othman, Samo & Kamboh, 2012):

$$KCO_2 = 0.24P + 0.74 \quad (17)$$

where KCO_2 are the emissions in kg CO_2/kWh; P power of diesel generator in kW, KCO_2 is equal to zero when $P = 0$.

The last substep of stage V is the analysis of the sustainability impact of the best solution, defining the making decision procedure. The strategy establishes different configurations (M), which could define the making decision stage, developing the techno-feasibility model. This block develops the study of the different approaches and possible configurations (M), which could be defined in the management system. The techno-feasibility model includes the analysis of the Cost of Carbon Abatement (CCA). It is the ratio between the difference of LCOE values between future situation and current situation (pump station with diesel generator) and the difference in CO2 emissions between the current case and the proposed strategy. CCA is defined by the following expression (Prakash, Ghosh & Kanjilal, 2020).

$$CCA(\in/t\ CO_2) = \frac{LCOE_M - LCOE_C}{CO_{2C} - CO_{2_M}} \quad (18)$$

where $LCOE_M$ is the LCOE value for configuration M in €/kWh, including the cost related to fuel; $LCOE_C$is the current LCOE value for the pump station €/kWh; CO_{2_C} are the CO2 emissions in $\frac{tCO_2}{kWh}$ for the pump station for the current situation; CO_{2_M} the CO2 emission for the configuration M in $\frac{tCO_2}{kWh}$.

3. Results

3.1. Case study

The data used for the analysis of this case study comes from an island called Great Stirrup Cay (GSC), located in the Berry Islands archipelago, The Bahamas. GSC is mainly used for tourism, where cruise ships disembark. Visitors are distributed in 58 villas and different areas of the island where there are attractions for the visitors. On this island, it is estimated that on average the quantity of visitors reaches a population of 5000 people and a stable population of 200 people. Likewise, the vegetation on the island is completely landscaped, is constantly irrigated and covers an area of approximately 2 hectares.

This case study will analyze the flow distribution according to the operating conditions of the island, as well as the current management standards of the distribution system. The entire distribution network is pressure supported by the pumping equipment, i.e., there are no elevations and/or structures that could cause the system to operate as a gravity system. The analysis elevations vary throughout the island from 7 m (as a minimum elevation) to a maximum elevation of 15 m.

This network is in The Bahamas and it has pumping equipment that maintains a constant pressure in the pipes. It consists of 2 different power pumps working in parallel, one with 5.15 kW (P-1) and the other with 11 kW (P-2). The highest efficiency point of the P-1 is found when it is working with 5.33l/s and 67.4 m w.c., obtaining an efficiency point equivalent to 0.75 with a speed of 3500 rpm. In contrast, the P-2, can obtain a maximum efficiency value at 3500 rpm of 0.78 when it is working with 12 l/s and 60 m w.c., Each of the pumps has a variable frequency driver (VFD) that is used to maintain the operating point of the equipment at 45 m w.c.

The supply pipelines are 4.5 km long and range from a maximum diameter of 100 mm to a minimum of 25 mm. All the pipes in the macro network are made of ductile polyethylene (HDPE). The 100 mm diameter mainline is equivalent to 1740 m, while the 50 mm and 25 mm pipes have 3309 m and 449 m, respectively. According to the records analyzed in the database, water consumption on the island will depend directly on whether there are visitors. The average daily consumption is 250m^3/day. Fig. 4

Fig. 5 shows the solar database estimated for the Bahamas Islands, showing the hourly data (Fig. 5a). The maximum irradiation varied between 0.67 and 0.86 kWh/m^2 in December and April, respectively. Fig. 5b shows the considered average temperature in the different months as well the average solar radiation each month. It varied between 0.186 and 0.273 kWh/m^2 in December and March, respectively.

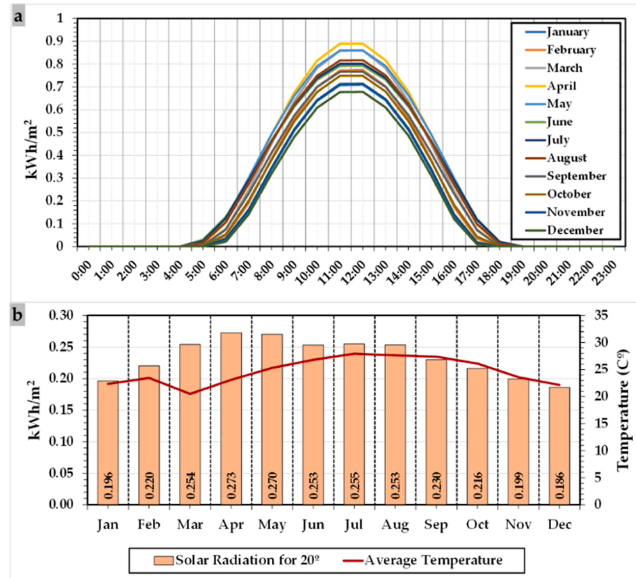

Fig. 5. Average solar radiation and temperature each month (a) Hourly (b) Daily.

3.2. Results

The strategy established a leakage calibration according to the recording database both counters and flowmeters. It enabled to discretize the best opening consumption point over time to discretize the consumed and leakage volumes. Fig. 6a and b show the chosen calibrated model, which was analyzed according to KPEV, which is defined in Table 3.

Table 3 shows the consideration greater than four openings to simulate the supply system in the model, established KPEVs, which were satisfactory. When the openings were lower than four openings the satisfaction degree was good or very good, getting the best calibration values for two openings. To define the leakage in the system, the emitter coefficient is 0.5 according to Adedeji, Hamam, Abe and Abu-Mahfouz (2017), considering the leakages equal to 5% (Creaco & Walski, 2017).

Fig. 7 shows the Newton-Raphson optimization procedure applied to pump systems for KPVE values, volume and annual injected energy. Fig. 7a shows the variation of Nash-Sutcliffe value (E) as a function of the iteration. These values oscillated between 0.92 and 1, being 0.97 as the median value in the first iteration. This range decreased rapidly in the sixth iteration when it oscillated between 0.98 and 1, being the median value equal to 0.994. All E values, which were obtained in the iteration procedure showed a very good fitness. It demonstrates the proposed strategy was able to estimate correctly the flow over time.

Fig. 7b shows a similar trend when RRSE value was analyzed. The median value decreased from 0.16 to 0.08 in the last iteration, being

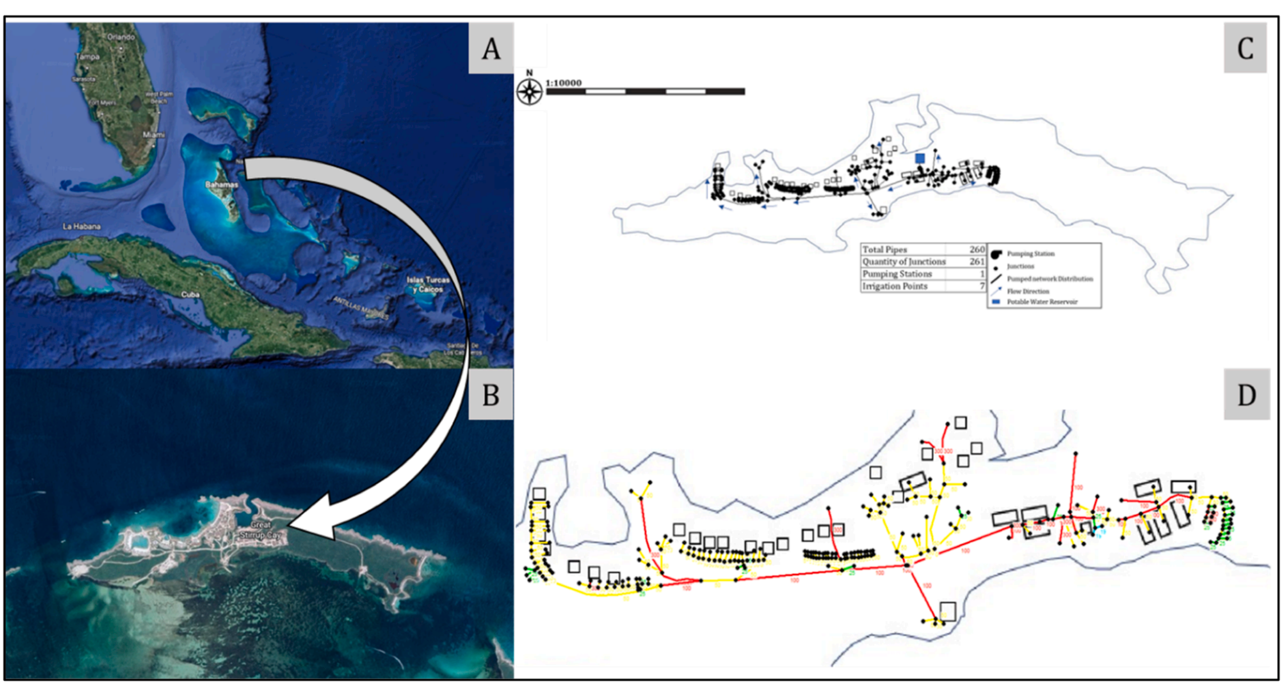

Fig. 4. Case study and hydraulic characteristics. (a) Global reference; (b) Satellite View; (c) Scheme of the Hydraulic Network; (d) Hydraulic Network.

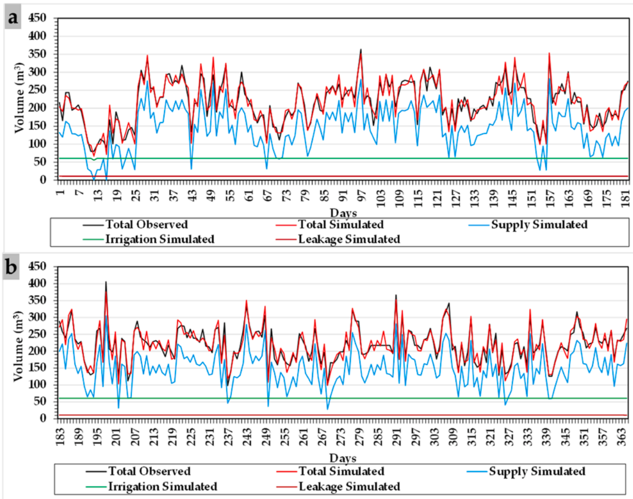

Fig. 6. Calibrated model compared with recorded values (observed), simulated and distribution between supply, irrigation and leakages. (a) From January to June; (b) From July to December.

more or less constant in the following iterations above the sixth. Maximum RRSE values around 0.2, establishing a very good fit according to criteria defined in Fig. 2.

Fig. 7c shows PBIAS value obtained when the strategy was applied to the case study. The PBIAS started the first iterations showing average values equal to 3.64% and it finished showing average values equal to 0.02. These values allow defining a very good fit with the recorded values according to Fig. 2. When flow was analyzed (Fig. 7d) the reached BIAS was 0.0007 in the final iteration when it started with average values equal to 0.087, showing a very good fit compared with the recorded values considering the criterion of Fig. 2.

Fig. 7e shows the variation in the pumped volume in the system. The optimization procedure improved the injected volume since the initial volume (observed) was 79,541 m^3. This value was coincident with the simulated value without an optimization procedure. When the model was optimized, the injected volume was 78,520.7 m^3, decreasing 1020.3 m^3 the leakage volume by adjusting the injected head. It implies the reduction of the used energy by pumps (Fig. 7f).

The injected energy without optimization was 21,404 kWh. The optimization procedure inside of the proposed strategy decreased the use of injected energy. This annual reduction was 6918 kWh, which represented above 32% of the current consumed energy and the CO2 emission was reduced 13.51%. The change in the regulation can be seen in Fig. 8a, which shows the variation of the rotational speed (the figure shows α coefficient, which defined the rotational speed of the machine)

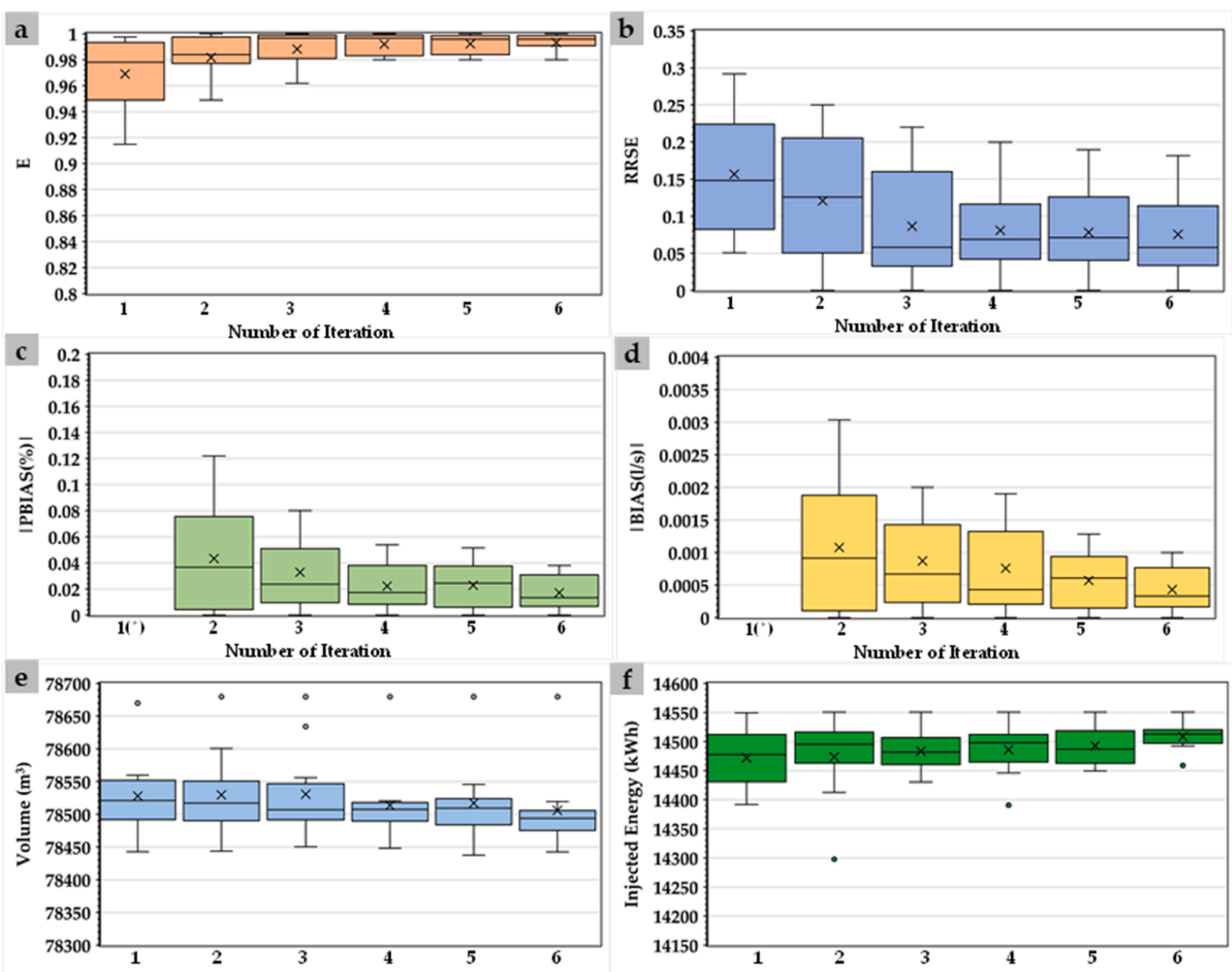

Fig. 7. Quartile evolution of the pumped optimization (a) E (b) RRSE (c) PBIAS percentage (d) BIAS flow in l/s (e) Injected volume in m^3 (f) Injected energy in kWh * Out of range.

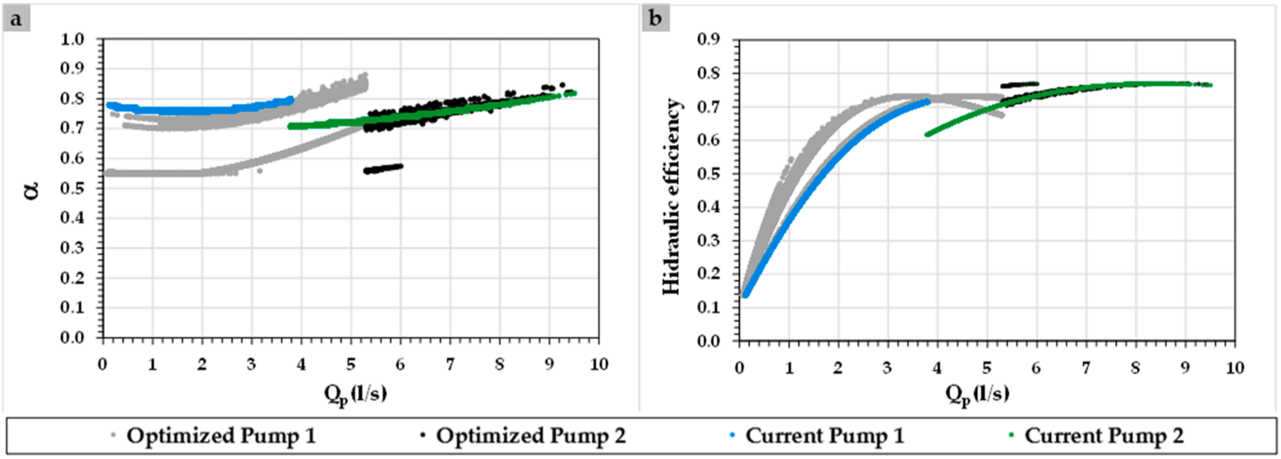

Fig. 8. (a) α coefficient as a function of pumped flow, (b) Efficiency as a function of flow and analyzed scenario.

for both pump stations as well as the variation of the hydraulic efficiency for the different operational points (Fig. 8b). Fig. 8a shows that Pump 1 changed its regulation zone from α values around 0.78 to values, which are grouped in two zones. In the first zone the α values oscillated between 0.7 and 0.88 for the flow range between 0 and 5.3 l/s. In the second zone, α changed from 0.55 to 0.7.

The optimization of Pump 2 was established for α values, which changed from 0.55 to 0.84 when the flow oscillated between 5.3 and 9.6 l/s. The efficiency (Fig. 8b) was not changed a lot in numerical values since it depends on the application of the affinity laws. These values changed from 0.2 to 0.7 when Pump 1 was analyzed. Pump 2 showed values, which varied between 0.6 and 0.78.

The knowledge of the optimized regulation of the pump systems enables the development of the optimized recovery locations (Step IV.a). This step includes the procedure of simulated annealing to locate different recovery systems in the water supply network considering four objective functions: theoretical recovered energy, leakage reduction, LCOE and NPV. Fig. 9 shows the results when the simulated annealing procedure was applied, considering from 1 to 10 recovery systems in the water network.

The annual theoretical recovered energy oscillated between 249.3 to 599.6 kWh from 1 to 10 recovery systems (Fig. 9a). The maximum value of energy was 704.8 kWh and the minimum 150.8 kWh. The maximum average value (599.6 kWh) represented 82% of the theoretical recovered energy compared with all lines that have installed recovery systems. The increase of recovered energy depicted a potential trend, showing the maximum increase of recovered energy between 1 and 3 recovery systems. When the number of recovery systems increased from 1 to 2, the increase of recovered energy was 36%. The increase from 2 to 3 recovery systems, the increase of recovered energy was 13.4%. The rest of the

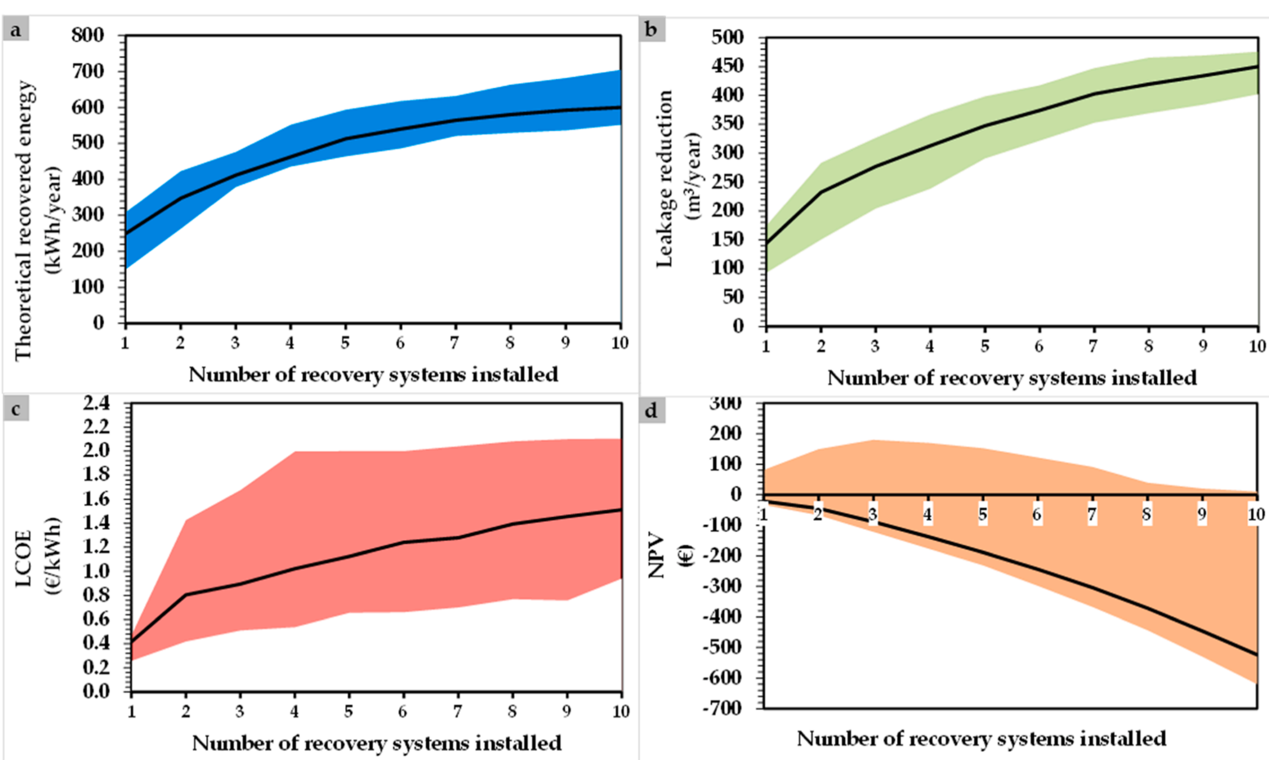

Fig. 9. Influence area between maximum and minimum as well as the average value (black line). (a) Theoretical recovered energy (b) Leakage reduction (c) LCOE and (d) NPV.

energy units were around 6% for each incorporation of the recovery systems until 7 units. When the number is greater than 7, the increase was around 2%. It implies the increase in LCOE values shown in Fig. 9c.

When leakage reduction was optimized (Fig. 9b), the average value oscillated between 144.3 m^3 (one recovery system) and 449.9 m^3 (ten recovery systems). The minimum value was 93.2 and the maximum value was 475.9 m^3. The decision to install 2 recovery systems implied a 66% of leakage reduction, while the incorporation of more recovery units caused a reduction of around 11%.

Fig. 9c shows the LCOE values for a different number of recovery systems. The average LCOE varied between 0.42 and 1.51 €/kWh. These values were above the developed studies by Timilsina (2021). It shows the low feasibility to install recovery systems in this case study, explained the topography of the water system is plain and the pumped system was optimized previously. The variation of the range of the LCOE values increased when the number of recovery systems was above two units. These variations can be seen in the shaded red area of Fig. 9c. This result is significant since it shows the penalization of the incorporation of new units into the system. If this figure is observed, the maximum LCOE values remain constant at around 2 €/kWh from 4 to 10 recovery systems.

Finally, Fig. 9d shows the NPV values for different recovery systems. The average values were negative in all scenarios (from 1 to 10 recovery systems). These NPV values varied from −21.8 to −523.5 €, respectively. The shaded orange area (Fig. 9d) shows that there are different situations, in which the installation of recovery systems could be feasible, but the inclusion of these hydraulic machines is not justified in feasible terms.

Fig. 10a shows the annual generated energy by PV systems as well as the injected energy over time. The figure shows both excess and deficit of energy throughout the day each hour. It shows the need to use batteries to supply the continuity of the demand. The maximum injected daily energy was 58.35 kWh, being the average energy equal to 39.86 kWh. The maximum instant power is around 7 kW. The PV systems supported 57.01 kWh as the maximum value while the average value was 48.38 kWh, being the maximum and average power equal to 7.65 kW and 3.69 kW, respectively.

Fig. 10b shows the hourly analysis for three days, particularly between 6th and 8th June. In this detail, the model considers the possibility of the cruise ships being present on the island, increasing the energy demand. The figure shows the theoretical recovered energy by micro-hydropower. It shows in this case study that hydraulic energy is residual and it is unfeasible, showing daily values of around 1 kWh. Fig. 10a shows the ΔDaily Energy. The proposed methodology enables the knowledge of the discretized values. Therefore, it will enable the intersection with others systems, which demand or generate energy to increase the self-consumption in the cities' communities. The techno-feasibility procedure developed a deep analysis of the feasibility considering both configurations (A without batteries and B considering batteries). It enables the managers to have a great wide variety to choose the best option. The strategy shows the best options to reduce the number of possible feasible solutions.

Fig. 11a shows the influence of the used area and discount rate when the current price of the energy was considered. The trend was inverse in Fig. 11b when future prices were considered, taking into account an increase of them. This hypothesis showed a decrease in the LCOE values when batteries are considered. Both figures show the different LCOE values, which were defined in the techno-feasibility procedure for different values of used areas and different values of real discount rates (k). When k was above 0.04 and the used area was above 1000 m^2, both configurations were similar, but when the used area was lower than 500 m^2, Configuration A (without batteries) showed best LCOE values than Configuration B.

This depicted trend changed when the increase in prices was considered. In this case, the LCOE was better when batteries were considered (configuration B) when the LCOE values oscillated 0.06 and 0.12 €/kWh for used areas between 300 and 500 m^2. The consideration of high values of discount rates ($k = 0.1$) showed the independency of the price in the best solution.

Fig. 11c shows a comparison between variations of prices when Configuration A was analyzed as a function of the used area for the different iterations of the techno-feasibility model. The increase of the energy fuel caused the increase of the LCOE values, being their values greater when the used area was smaller.

Fig. 11d shows the variation of the photovoltaic energy ratio (PVER). This index shows the ratio between photovoltaic energy used for the pump station and the necessary energy for the pump station. In this case, PVER oscillated between 0.08 and 0.33 when the used area was 11.8 and 6000 m^2 respectively. Therefore, the analysis developed by the proposed methodology showed the increase of the used area for PV systems does

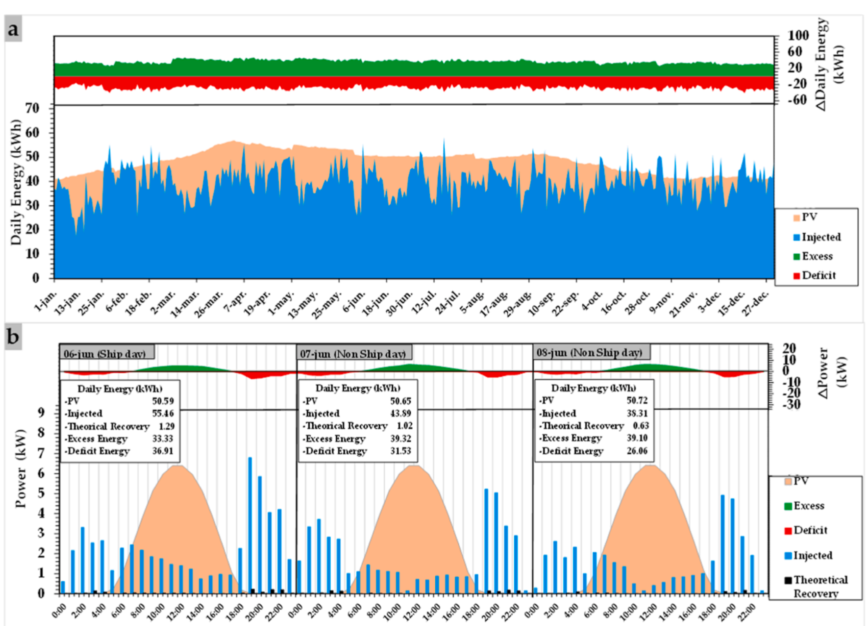

Fig. 10. Analysis demanded and generated power for used area equal to 150 m^2. (a) Daily annual values (b) Detail of three days.

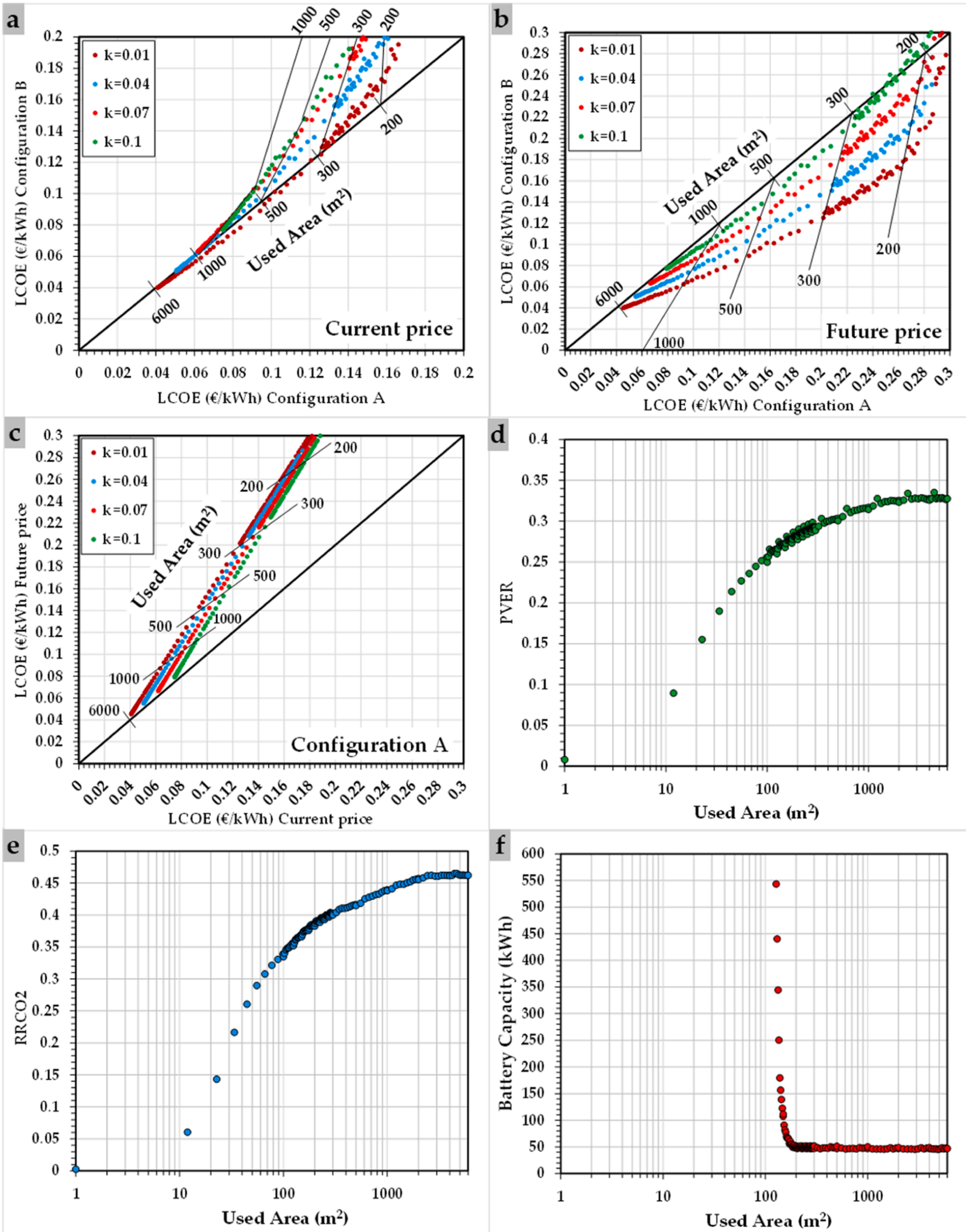

Fig. 11. (a) LCOE values when current prices are considered (b) LCOE values when future prices are considered (c) LCOE values for current and future prices when Configuraton A is chosen (d) PVER for configuration A; (e) RRCO2 for configuration A; (f) Variation of batteries needs as a function of the used area.

not guarantee the self-consumption in this case of the pump stations although the system can generate an excess of energy higher than consumed (Fig. 10). This show the need to complement other renewable systems different to solar and hydro, such as wind or tide.

Fig. 11e shows the ratio of the reduction of CO2 emissions (RRCO2). This ratio is the estimation of the decrease of CO2 emissions, considering the renewable energy generated by the hybrid renewable system. These values oscillated between 0.06 and 0.46 when the used area was 11.8 and 6000 m^2 respectively. This reduction could be around 40% for used area of around 500 m^2. This value could be a solution for this case study applied.

The need of battery capacity to take advantage of all generated energy using renewable energy systems is shown in Fig. 11f. It is minimized to values around 50 kWh for a used area greater than 200 m^2. The reduction of the battery needs is crucial to increase the feasibility of the solution.

Fig. 12a shows the variation of the cost of carbon abatement (CCA) values when configuration A was analyzed for the different used areas, considering different discount rates as well as two scenarios, current future prices. When the current price of diesel was considered, the maximum CCA was between 1800 and 2200 €/tCO_2 for $k = 0.01$ and $k = 0.1$, respectively. The maximum values were stable for a used area greater than 2000 m^2. These values are high if they are compared with the review analysis developed by Blum et al. (2013). High values indicate that there is a high increase in renewable power cost to reduce the CO_2 emissions in modest values. In this case, the CCA indicates the most sustainable used area should show CCA values under 400 €/tCO_2 according to Blum et al. (2013). This CCA is higher because there is solar energy, which is not considered by the pump station. This energy should incorporate into other consumption roles, which increase the CO2 emissions as well as the LCOE. Table 4

The CCA values were greater than current prices when the future prices were considered for different discount rates. When configuration B was analyzed (Fig. 12b), CCA values oscillated between −2900 and 4000 €/tCO_2 as a function of the discount rate as well as the price scenario (i.e., current or future). When current prices were analyzed, the maximum CCA oscillated between 1600 and 2000 €/tCO_2, showing uniform values for the used area above 1000 m^2. This configuration showed the need to introduce more energy consumption to maximize the use of the renewable systems, decreasing the CCA value and increasing the impact of the reduction of CO2 emissions when renewable systems are used.

4. Discussion

The previously defined methodology was applied to a particular case study. However, the strategy could be replicated in any case study if the input data are known. To do so, the recorded values of consumption nodes and/or recorded values of the main flowmeters must be known. If managers know these values and the topology of the network, by implementing this strategy they will be able to define the best regulation rules to minimize energy consumption and establish the best decision-making to integrate hybrid systems, generating a mini-grid. The use of renewable energy systems is spread in the world by public financial programmes (Come Zebra, van der Windt, Nhumaio & Faaij, 2021). As instance, countries like India are using biomass, solar and hydropower systems to supply its needs (Narnaware & Panwar, 2022). Sri Lanka and Nepal are getting behind by hydropower stations in free channels to supply isolated communities (Dhaubanjar et al., 2021). Caribbean areas work on the development of sustainable tourism since 1995, proposing new clean technologies to reduce the impact of the natural resources (Yaw, 2005). The research presented in Eras-Almeida and Egido-Aguilera (2019) developed comparative analysis of the mini-grids in different islands located in the Atlantic and Arctic, Pacific and Indian Oceans, and the Caribbean and Mediterranean Seas. Unlike the previous cases, the renewable energy systems presented in these studies are not aligned with the water distribution system. The proposal of this research enables the alignment between water distribution systems and the mini-grid, to take advantage of all residual hydraulic energy of the system to convert it to the electrical grid to be consumed in the water systems (e.g., pumps) or other consumption points if there is excess of generated energy. In this sense, this work presents a novelty, integrating a making decision tool inside of the supply system to optimize the energy consumption as well defining the feasibility of the recovery systems considering photovoltaic systems.

The main key of this research is the definition of a novel optimized strategy, which integrates the calibration model of the water system through a random opening of consumption nodes to adjust the consumption pattern of the model to the volume recorded over time and the partial flowmeters of the network. The proposal is capable to estimate the opening time of each consumption node both irrigation and supply over time. It analyses the feasibility of the hybrid systems, considering the constraints of the case study as well as the leakages of the supply system. Furthermore, he leaks influence the selection of the hydraulic machine as well as the optimization of the regulation rules. The proposal includes a decision-making tool, which enables the sustainable

Table 4
KPEV values for calibration.

Number of openings	E	RRSE	|PBIAS| (%)	|BIAS|(l/s)
1	0.95	0.23	0.10	0.21
2	0.90	0.32	0.01	0.02
3	0.81	0.44	0.01	0.01
4	0.67	0.57	0.10	0.21
6	0.37	0.79	0.15	0.33
8	0.20	0.89	0.10	0.23
12	−1.03	1.42	0.27	0.59
24	−7.94	2.99	0.74	1.61

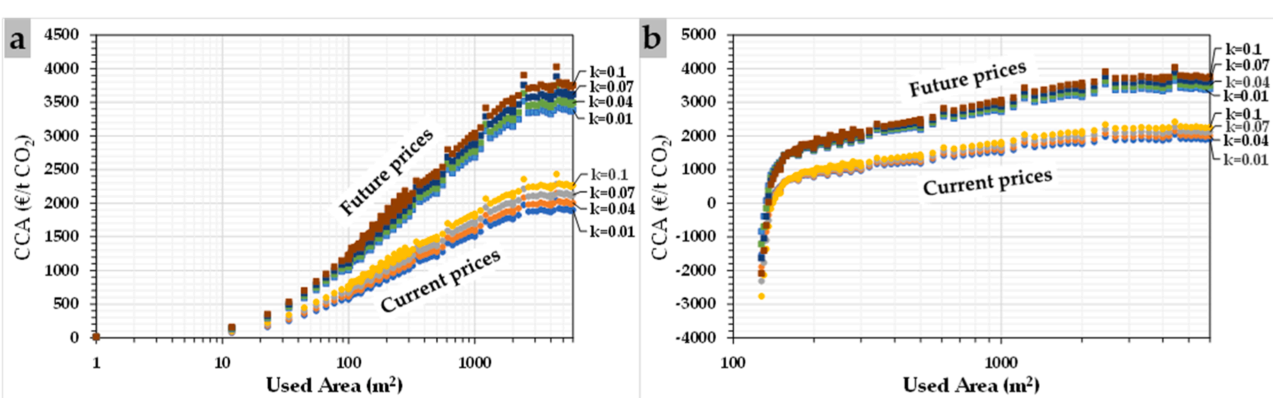

Fig. 12. (a) CCA values for configuration A (b) CCA values for configuration B.

improvement of the city's management. The integration of the reduction of leaks, the generation of clean energy and the minimization of the consumed energy in the water supply system is crucial to reaching the different targets of the SDG-11 towards the sustainable management of cities.

5. Conclusions

The newly developed methodology enables the inclusion of a double simulated annealing procedure to develop an integration of renewable energy systems (i.e., solar, hydro, among others) inside of water distribution systems in cities. It includes a Raphson-Newton optimization to minimize the energy consumption by the definition of the best regulation rules to guarantee the quality and quantity of demand service. In addition, the optimization procedure enables the chosen techno-feasibility options to be implemented in real case studies. The optimization procedures allow the inclusion of new hybrid systems as well as the integration of new energy demands of the city, to be considered in the generation, consumption and battery capacities.

The proposed methodology is focused on defining the possibility of self-consumption in any system evaluating the different alternatives of clean energy (e.g., solar, hydropower, among others) once the water managers know the topology of the network as well as the recorded values of flow, calibrating the model previously. The procedure has a high optimized potential since it can be applied to any case study (isolated or not), analyzing the range of sustainability improvement in any case, considering economical, technical and environmental considerations. The possibility of replicating this methodology in any world case study is conditional on knowing the topology, having a record of consumption data and knowing the supply network operation restrictions. If these three parameters are known, the self-consumption ceiling of the analyzed system can be determined, taking into account other renewable energies and the economic parameters of the study area.

The research demonstrated the high powerful to be used in real case studies. It was applied in a real case in The Bahamas. The optimization reached the reduction of energy consumption above 30%, improving the regulation rules. Besides, the analysis of renewable energy systems showed no feasibility to install microhydropower systems, but it could support 2% of the consumed energy. In contrast, the use of PV panels could guarantee 32% self-consumption and green management could reduce 40% of the tones of CO_2 compared with the use of the diesel generator. The strategy is open to include other renewable systems such as tides or wind turbines to increase self-consumption in all activities in The Bahamas. The strategy helps to mitigate the energy impact of the cruise ships, contributing to the development of SDG-11, called sustainable cities and communities.

The future works can be integrated into research lines, that develop an algorithm to digitize all information to improve the reading of data as well as the monitoring the measures control of the water system. These new algorithms will help to integrate different energy needs of the management system (i.e., water systems, lighting system, neighbor's community, among others) for sharing the excess of generated energy by renewable energy in the cities. Digitalization combined with programming tools implies the improvement of knowledge about consumption patterns, and therefore, the best definition of the use of natural resources as well as the correct dimensioning of the renewable energy systems for the urban cities. If the future works are focused on water areas, the integration of the sustainable indicators and green rating systems could help to define new sizing/management methods, which consider sustainability in the integration of the different constraints (i.e., demand, regulation definition, materials, among others). This will also help managers to achieve Sustainable Development Goals in water distribution systems, with all environmental, economic and social implications involved in cities.

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CRediT authorship contribution statement

Angel V. Mercedes García: Validation, Formal analysis, Writing – original draft, Writing – review & editing. **Francisco-Javier Sánchez-Romero:** Conceptualization, Methodology, Software, Validation, Formal analysis. **P. Amparo López-Jiménez:** Writing – original draft, Writing – review & editing, Writing – original draft, Writing – review & editing. **Modesto Pérez-Sánchez:** Conceptualization, Methodology, Software, Validation, Formal analysis, Writing – original draft, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

Data will be made available on request.

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