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Conditions accommodating a dominant stakeholder in the design of renewable air conditioning systems for tourism complexes

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ABSTRACT

Seawater air conditioning systems use cold water from the deep ocean to provide cooling utilities to buildings. Their design, as with other renewable energy systems, involves the participation of multiple stakeholders with different preferences and objectives. A multi-objective strategy based on compromise solutions for reducing the dissatisfaction between multiple participants is presented. The dominant stakeholder is considered to have predominant participation, opinion, and weight in the final decision of the project. The presented decision-making framework allows for the resolution of conflicts and shows the effects of different criteria on the final configuration of the system. This work presents an optimal design model considering, as a case study, a touristic zone in Mexico. The results show significant differences between scenarios where all the stakeholders are considered under a condition of equality and one in which only the dominant stakeholder is considered. This decision-making approach shows flexibility and provides tolerance limits for compromise solutions that still consider the influence of the dominant stakeholder.

1. Introduction

Despite the significant economic contribution that the tourism industry represents, this sector requires high energy consumption [1]. Of the total energy consumption, 40% is associated with the operation of air conditioning systems [2]. This results in considerable generation of greenhouse gas emissions [3]. These factors have motivated alternatives based on renewable sources and the development of efficient cooling technologies [4]. Consequently, the social participation of public and private actors for promoting and designing strategies based on clean and efficient energy supply has been stimulated [5]. Social participation is remarkable in regions where tourism is the central economic activity. In these communities, the local population depends on revenues generated by the hotel industry. To promote social development, government entities provide funds and propose policies for improving the tourism infrastructure [6]. Therefore, due to the social impact of tourism activities on these communities, new energy projects have been the object of social discussion and participation [7].

From a technological point of view, recent works have presented proposals for improving the energy efficiency of air conditioning systems. Wu et al. [8] presents a strategy for coupling operational policy and demand scheduling. Tang et al. [9] proposes an optimal control strategy for managing the cooling load during low consumption periods. In the current literature, different works have addressed aspects related to energy saving, the environment and economic viability of different air conditioning systems compared to the conventional compressed air-conditioning system (AC). Qi & Lu [10] present an energy efficiency proposal through the implementation of air conditioning with liquid desiccant reducing the energy consumption compared to conventional AC system. Liu et al. [11] analyzed the economic feasibility of implementing a system operated with biogas compared to conventional AC. Zhao et al. [12] focus on the reduction of greenhouse gases resulting from the use of refrigerants in the conventional AC through the calculation of carbon footprint to reduce emissions by this concept. In the same sense, exergy analysis of conventional compressed air-conditioning systems (AC) has also been performed [13]. Other proposals have addressed clean alternatives for reducing the dependence on fossil fuels [14].

On the other hand, alternatives that do not require artificial refrigerants, such as systems based on seawater, have been proposed [15]. The use of energy from the oceans, as waves and tides,

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Nomenclature

Variables

TAC	Total annual cost, $/year
GHGE	Total Greenhouse gas emissions, t CO2 eq./yr
CS	Compromise solution
DS	Dominant stakeholder (solution)
$\alpha 1$	Normalized economic function
$\alpha 2$	Normalized environmental function
HeateCost	Total cost of heat exchangers, $
PipingCost	Piping costs, $
Pumpequip	Total cost for the pumps, $
PumpingCost	Total pumping cost, $
ElectricityCost	Total cost for electricity, $
BiocideCost	Biocide cost, $
ChemicalCost	Chemical cost, $
MaintCost	Cost of maintenance, $
$\eta_{k,t}^{HE}$	Heat exchanger efficiency
Ghgelect	Total emissions generated by the conventional AC, t CO_2 eq./yr
GhgeSwac	Total emissions generated by the SWAC system, t CO_2 eq./yr
S_t^{ocean}	Seawater taken from the ocean, m^3/day
S_t^{trat}	Treated seawater in the plant, m^3/day
$S_{k,t}$	Seawater flowrate in hotel k in time t, m^3/day
$S_{k,t}^{out}$	Seawater out flowrate from hotel k in time t, m^3/day
S_t^{neut}	Seawater treated in the neutralization system, m^3/day
F_t^{bio}	Flowrate of biocide, m^3/day
F_t^{chem}	Flowrate of chemical, m^3/day
$Q_{k,t}^{water}$	Heat load removed by the seawater, kWh/day
$Q_{k,t}^{ac}$	Heat load removed by conventional AC in time t, kWh/day
$\mathrm{COP}_{k,t}^{ac}$	Coefficient of performance for conventional AC system in time t
$PL_{k,t}^{ac}$	Part load for conventional AC system in time t
Q_k^{emax}	Maximum heat load in the conventional AC system in all times, kWh
Q_k^{qwm}	Maximum heat load in the SWAC system in all times, kWh
A_k	Heat exchangers area, m^2
Cost_k^{unit}	Unit cost for heat exchangers, $
Pcf^{trat}	Unit cost of pipeline used to extract the deep seawater, $
Pcf_k	Unit cost of pipeline from treatment plant to hotel k, $
Pcf_k^{out}	Unit cost of pipeline from hotel k to neutralization plant, $
Pcost1	Unit cost of pump used to extract the deep seawater, $
$Pcost2_k$	Unit cost of pump from treatment plant to hotel k, $
$Pcost3_k$	Unit cost of pump from hotel k to neutralization plant, $
$Cost_{k,t}^{e}$	Cost paid to the local electricity company, $/day
$Emelec_{k,t}$	Emissions for the use of electricity, t CO_2 eq./day
$Power_t$	Power used to extract the deep seawater, kW
$Power2_{k,t}$	Power used to seawater distribution form the treatment plant to hotel k, kW
$Power3_{k,t}$	Power used to seawater distribution from the hotel k to neutralization plant, kW
TotalPower	Power consumed in the pumps, kW
EnergyPump	Total energy consumed by the pumps, kWh

Parameters

TAC^{UB}	Upper total annual cost, $/year
TAC^{LB}	Lower total annual cost, $/year
$GHGE^{LB}$	Lower total Greenhouse gas emissions, t CO_2 eq./yr
$GHGE^{UB}$	Upper total Greenhouse gas emissions, t CO_2 eq./yr
$\mathrm{econsm}_{k,t}$	Total electric input spent with conventional AC system, kWh
COP	Coefficient of performance
$\mathrm{Q}_{k,t}^{\mathrm{HR}}$	Heat load to be removed from the air in hotel k in time t, kWh
$Elect_{k,t}^{e}$	Energy consumption from the public grid, kWh/day
ρ	Density of seawater, kg/m^3
Cp^{sw}	Heat capacity of seawater, kJ/kg° C
ΔT	Temperature differential, °C
$\mathrm{C}^{\mathrm{bio}}$	Biocidal concentration, kg/m^3
C^{in}	Commercial biocide concentration, kg/m^3
$\mathrm{Q}^{\mathrm{max}}$	Upper bound for the heat load, kWh
$\mathrm{S}^{\mathrm{tmax}}$	Upper bound for the flowrate in treatment plant, m^3
$\mathrm{S}_k^{\mathrm{max}}$	Maximum flowrate in hotel k in all times, m^3
$\mathrm{S}^{\mathrm{hmax}}$	Upper bound for the flowrate in each pipe segment, m^3
U	Global heat transfer coefficient, W/m^2 °C
ΔT_{ml}	Logarithmic mean temperature difference, °C
$\mathrm{VCost}_k^{\mathrm{unit}}$	Variable cost for the heat exchangers, $
FCost_k^{unit}	Fixed cost for the heat exchangers, $
δ	Exponent for heat exchangers area cost
k_F	Factor used to annualize the capital costs, yr.$^{-1}$
D	Pipeline diameter, m
L	Length of pipeline, m
k_m, m	Pipe cost parameters that depend on the pipe material
$\mathrm{CVP}^{\mathrm{pump}}$	Variable cost for pumps, $
$\mathrm{CFB}^{\mathrm{pump}}$	Fixed cost for pumps, $
H_Y	Hours of operation per year, hrs./yr
$\mathrm{PFC1}_t$	Pumping cost from deep ocean to treatment plant, $\$/m^3$
$\mathrm{PFC2}_{k,t}$	Pumping cost from treatment plant to hotel k, $\$/m^3$
$\mathrm{PFC3}_{k,t}$	Pumping cost from hotel k to neutralization plant, $\$/m^3$
η	Pump efficiency
f	Friction factor
UCE	Unitary cost for electricity, $/kWh
ξ	Unit cost for biocide, $\$/m^3$ of treated seawater
γ	Unit cost for chemical, $\$/m^3$ of treated seawater
β	Unitary cost per maintenance, $
τ	Maintenances per year
ϕ_{GHGE}	Emissions factor, kg CO_2/kWh
Ω	Slope in the linear regression obtain for each pump
Ψ	Intercept in the linear regression obtain for each pump

Binary variables

y_k^{he}	Used to determine the existence of heat exchangers
y^{trat}	Used to determine the existence of pipeline segment from the ocean to the treatment plant

y_k^{hotel}	Used to determine the existence of pipeline segment from the treatment plant to each hotel
y_k^{out}	Used to determine the existence of pipeline segment from the hotel to the neutralization plant
y^{main}	Used to determine the existence of maintenance

Sets

k	Hotels
t	Period of time in days

Acronyms

AC	Compression air conditioning
SWAC	Seawater air conditioning
COP	Coefficient of performance
C-VaR	Conditional value-at-risk
NPV	Net present value
HDPE	High-density polyethylene
TAC	Total annual cost
GHGE	Greenhouse gas emissions
LB	Lower bound
UB	Upper bound

as well as its thermal gradient, provides alternatives for producing clean energy [16]. In recent years, reliable energy systems based on ocean energy resources have been implemented without significant environmental impact [17]. Ocean thermal energy conversion takes advantage of the temperature gradient between the warm surface (heated by solar radiation) and cold deep layers of the ocean to generate electricity [18]. Considering air conditioning, seawater AC (SWAC) systems offer a promising technology for providing cooling utilities using deep seawater at low temperature (see Fig. 1) [19].

From an economic point of view, SWAC systems, due to their low electric consumption, are less affected by energy price variations than are conventional AC systems [20]. Another economic advantage of SWAC systems is their short payback period (three to seven years) [21]. Because of the reduction in electric consumption, the CO_2 emissions for cooling can be reduced by 90% and simultaneously reduce the environmental impact associated with conventional AC operation using refrigerants [22].

Using deep seawater for cooling purposes requires technical, economic, and operational considerations [23]. In this context, different approaches have been developed in order to demonstrate the cost-effectiveness of these systems. Elsafty & Saeid [24] analyzed these systems from the economic point of view based on the simple pay back and the net present value (NPV) methods. In energy terms, Surroop et al. [21] compared the conventional AC system with the seawater-based system; they conclude that using the second system the energy consumption is reduced. Another important advantage that makes these systems profitable is addressed from an environmental point of view. The substitution of refrigerants by cold seawater and the reduction of electricity consumption requirements allows the emission of greenhouse gases reduction [25].

Other proposals have been focused on improving efficiency by developing empirical models for the operational policy-making to predict the operation of such systems [26], as well as the addition of equipment or improvements in the process [27]. In the same sense, other studies have been oriented to take advantage of using deep seawater for secondary applications. Von Herzen et al. [28] consider the feasibility of an integrated air-conditioning, desalinization, and marine permaculture system, which would also supply chilled fresh water to end users. All these studies have in common the conclusion that using deep seawater for cooling has a high potential for reducing the energy consumption and emissions associated with this concept.

The design and implementation of new systems or the application of new technologies, such as SWAC systems, is a complex decision-making process in which multiple conflicting objectives, including social, economic, political, and environmental, are involved [29]. It is important to realize that stakeholders have biased opinions and perceptions that will influence their final decision. The opinions generally reflect different criteria, priorities, and interests regarding the design and operational objectives. The last goal in a multi-stakeholder decision-making setting is to make a final decision that reaches a form of consensus [30]. Different

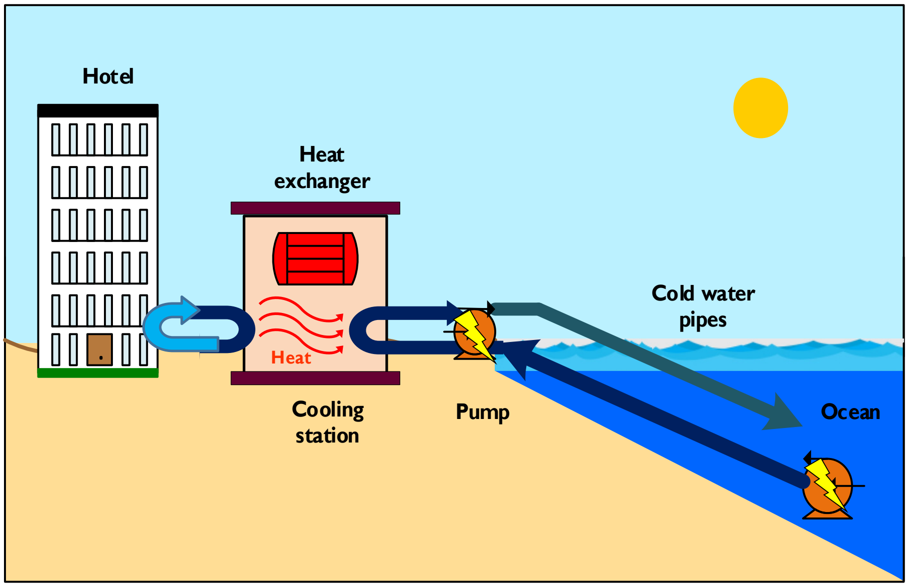

Fig. 1. Seawater air conditioning schematic.

works have addressed this subject; a multi-stakeholder decision-making approach was recently presented by Smith et al. [31]. They used the singular value decomposition method for multi-objective decision support, where a set of weights that satisfy certain rules are used to obtain a compromise solution. Another study was presented by Dowling et al. [32]; who analyzed a multi-objective approach for multiple decision takers, proposing to find a compromise solution and reduce dissatisfaction of the users. Gonzalez-Bravo et al. [33] proposed a geometrical approach for reducing the dissatisfaction level between multiple stakeholders. Fuentes-Cortés et al. [34] used the C-VaR approach for analyzing the performance of distributed energy systems. Sánchez-Bautista et al. [35] presented a multi-stakeholder optimization approach to accommodate economic, environmental, and social objectives; however, they considered that each stakeholder had the same weight in the decision-making process. Generally, the strategy for proposing solutions in the multi-stakeholder framework is to reach a compromise solution that can reduce the levels of dissatisfaction of the participants in multi-criteria decision-making, or at least, to identify a solution that shows the tradeoffs between the preferences of the participants.

A common approach is to define the conflict between the multiple stakeholders as an equilibrium condition under which all the involved parts have the same level of importance over the final solution of the problem, and the same level of participation in the discussion. However, actual conflict conditions are defined by a remarkable imbalance between the participants [36]. In the conflict decision-making framework, the normal condition is giving priority to a dominant stakeholder in the final decision. This dominant stakeholder is defined by the context of dependence of the new project [37]. If the source of investment is a private firm, it is possible that the new project could lose support if the equilibrium solution represents a big economic sacrifice considering the interests of the stakeholder [38]. Projects financed by the community or using public and government funding could have a different perspective oriented to social or environmental impacts [39]. Mixed funding is determined by the main investor: the one offering the main source of funding. The willingness of this dominant participant determines the final implementation of the project, even when the rest of the parts are not considered in the final decision, because it is possible that the main source of funding could be withdrawn [40].

In this work, the multi-criteria decision-making environment is addressed considering the next issues:

- The individual interest of the dominant stakeholder. It is expressed using a solution defined by the levels of priority over different objective functions.
- The difference between the individual interest and the compromise solution obtained assuming that all the stakeholders have the same level of importance in the final configuration of the system.
- A pondered compromise solution where all the stakeholders are included, considering their specific level of participation in the final decision, while identifying the dominant stakeholder (most weight) in the system configuration.

This paper presents a strategy for reaching a solution by which the dominant stakeholder can determine the level of change on its solution for dealing and negotiating in a multi-stakeholder conflict decision-making framework. This strategy allows determination of the level of influence in the final solution of different stakeholders. In addition, it allows obtaining a solution according to the dominant stakeholder preferences, while considering the other participants.

1.1. Description of the technological proposal

SWAC systems have as their main components pumps, heat exchangers, and pipelines. Seawater is pumped from the deep ocean (cold-water intake pipe, may go down 1000 m to reach water at 4 °C) to a holding basin, where a biocide is added to reduce biofouling in the equipment. Subsequently, the cold seawater is pumped and passed through a heat exchanger (made of titanium). Finally, the cold water is distributed for air conditioning. After the seawater has absorbed a certain amount of heat from the rooms, it is sent to a treatment facility to neutralize the biocide (through an outtake pipe), and then returned to the sea at a temperature similar to that of the surface water to avoid thermal pollution. It is typical that all the pipes are made of high-density polyethylene (HDPE). Nevertheless, if there is not enough cold water in a given time period to provide the required cooling demand, or if a hotel decides not to use this utility, conventional AC systems are available that use electricity from the grid. Moreover, this auxiliary system is also available during shut-down periods when planned maintenance is carried out.

The paper is organized as follows: In the Methods section, the strategy and solution sequence used to address the multi-objective problem in a multi-stakeholder environment is described. The problem statement is explained in the Optimization strategy section. In the Multi-stakeholder strategy section, the method for solving multi-objective problems in a multi-criteria decision-making framework is developed. A mathematical model that includes mass and energy balances, nonlinear equations, constraints, and objective functions representing the addressed problem, is developed in the Multi-objective optimization section. Finally, in the results section the system configuration (seawater and energy requirements and heat exchanger size) is obtained after considering all stakeholders under an equality assumption and considering the dominant stakeholder.

2. Methods

In this section, the modeling framework used for addressing the multi-criteria decision environment is described. This includes the strategy for considering the dominance conditions, and the operational and design constraints of the SWAC system used for the proposed case study.

2.1. Optimization strategy

The optimization strategy used to address the multi-stakeholder environment is shown in Fig. 2. The process data are used to feed the model. Data include the electricity used for the cooling utilities (at each of four hotels located in Cancun, Mexico), the electricity price, and the cost of the equipment for each SWAC system. This includes as well, the mechanical maintenance cost, the unit cost for the biocide, and end-of-pipe treatment chemicals. In this work, two objective functions used to assess the economic and environmental performance of the SWAC system are considered. The first one involves minimization of the total annual cost of the system (TAC) while the second function involves minimization of greenhouse gas emissions (GHGE). The optimization sequence is as follows (see Fig. 3).

The optimization problem was solved individually as a Mono-objective optimization to obtain the extreme optimal solutions of the Pareto front. These solutions allow the two objective functions to be scaled. After that, the priorities of the stakeholders with respect to each objective are considered to formulate solutions

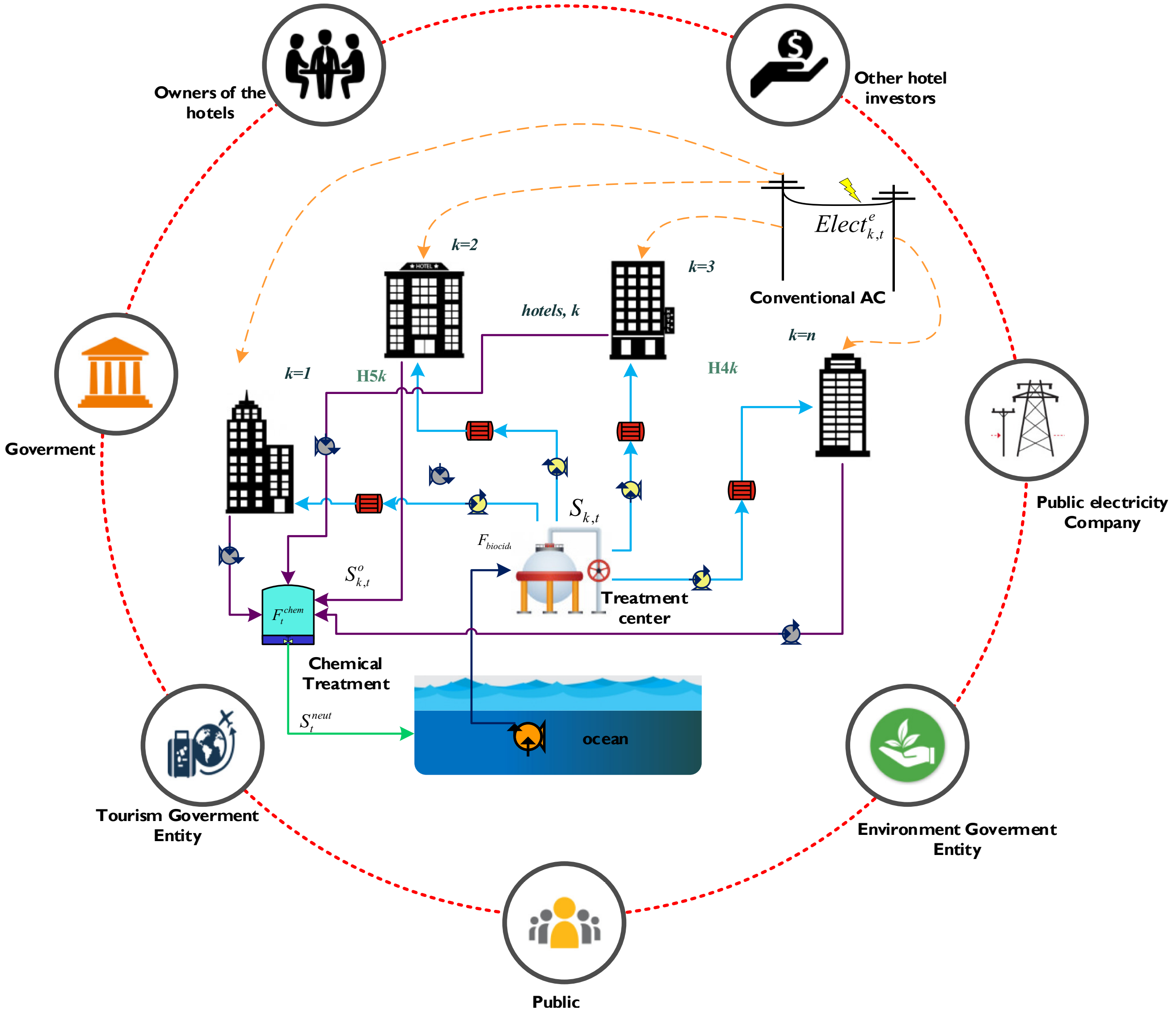

Fig. 2. Stakeholder decision-making process in SWAC system design.

according to their criteria. This results in a set of Pareto optimal solutions. Next, the proposal of the dominant stakeholder is evaluated without considering the rest of the participants. Subsequently, a solution is obtained, where all stakeholders have the same weight under a condition of equality. Finally, a compromise solution is obtained. In this solution the dominant stakeholder yields enough to reach a consensus with all the other stakeholders involved in the decision-making process.

2.2. Multi-stakeholder strategy

The proposed model is an example of mixed integer nonlinear programming (MINLP) and can be formulated as a multi-objective problem. This formulation seeks to minimize simultaneously the total annual cost (TAC) and the overall greenhouse gas emissions (GHGE), of which each component of both objectives is described later. Because the two objectives are in conflict, it is necessary to identify a set of solutions in a Pareto front. There are different methodologies for solving multi-objective problems. In this case, the compromise solution is proposed based on the utopia-track approach, which involves obtaining an optimal value that satisfies all the involved parties; this solution is a Pareto optimal solution [41]. The compromise solution is defined as one that achieves a suitable trade-off among the criteria or preferences of the participants in the multi-criteria decision environment [32].

First, each objective function is solved independently to obtain the lower bounds (LB) of each function (TAC^{LB}, $GHGE^{LB}$). The results define the coordinates of the utopia point, which, in general, corresponds to an infeasible solution, because the two objectives are in conflict. In addition, the solution of the objectives also defines the upper bounds (UB: TAC^{UB}, $GHGE^{UB}$), which define the coordinates of the nadir point. The coordinates of the nadir point and the utopia point allow us to scale the objective functions and find the solution on the Pareto front that is closest to the utopia point. This solution is the compromise solution.

The objectives are scaled using variable α:

$$\alpha_1 = \frac{TAC - TAC^{LB}}{TAC^{UB} - TAC^{LB}} \tag{1}$$

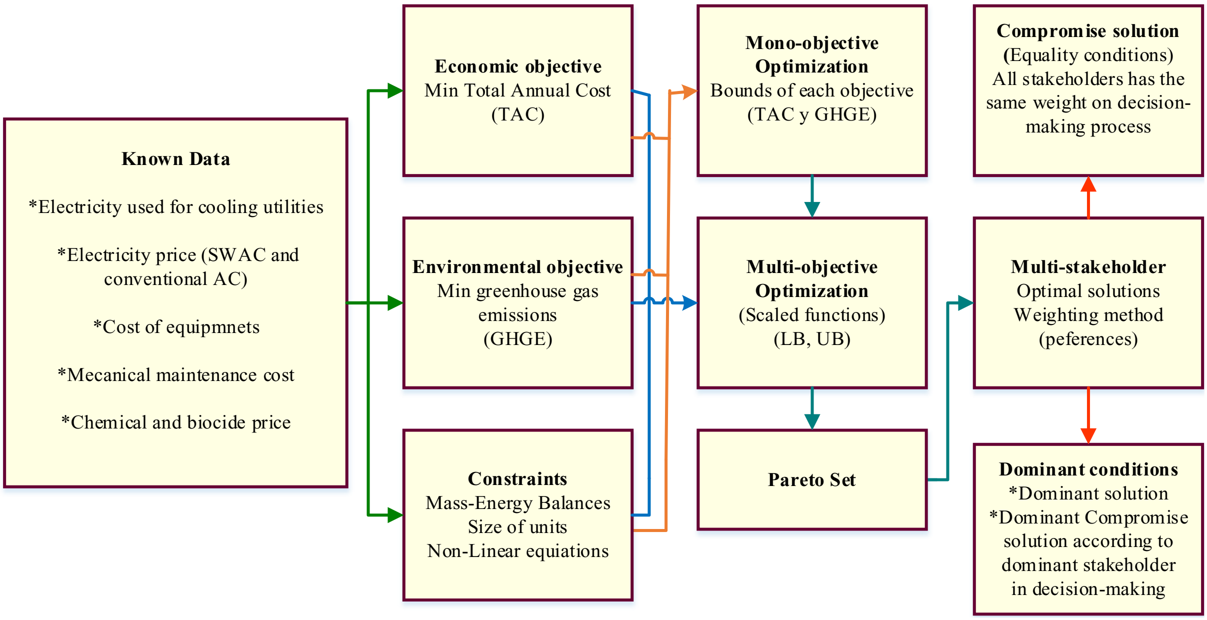

Fig. 3. Solution sequence flowchart.

$$\alpha_2 = \frac{GHGE - GHGE^{LB}}{GHGE^{UB} - GHGE^{LB}} \tag{2}$$

St. $0 \le \alpha_i \le 1$.

The level of preference about an objective function is defined by a weight coefficient $(\omega, 0 \le \omega_i \le 1)$. This leads to obtaining a criteria solution for each stakeholder (Cr).

$$Cr = \sum_{i=1}^{I} \omega_i \alpha_i \tag{3a}$$

$$\sum_{i=1}^{I} \omega_i = 1 \tag{3b}$$

where the index $i = 1, 2 \ldots I$, denotes the number of objective functions and ω is the weight associated with the level of preference over the objective function.

Considering a set of stakeholders where J participants are included, the individual stakeholder solutions are defined by the expression (3c).

$$Cr_j = \min \sum_{i=1}^{I} \omega_{i,j} \alpha_i \tag{3c}$$

The individual optimization process for computing the solutions associated with the criteria of the stakeholders, leads to obtaining a set of values of α. The average of the different values of α is computed using the next expression:

$$\overline{\alpha_i} = \frac{\sum_{j=1}^{J} \alpha_{i,j}}{J} \tag{4}$$

This leads to the compromise solution (CS) shown in Equation (5). It is defined by the nearest optimal solution to the average values of the set of normalized objective functions α [34]. It results in minimizing the sum of the difference between the average value of the set of normalized objective functions and the multi-objective solution defined by the scaled objective functions α.

$$CS = \min \sum_{i=1}^{I} \left| \alpha_i - \overline{\alpha_i} \right| \tag{5}$$

This solution represents a point on the Pareto front that accommodates the priorities of all the stakeholders. Because it is derived from the average values associated with the criteria of the multiple stakeholders, it results in a consideration of equality among the solutions obtained based on individual preferences of the stakeholders. In addition, because it is based on the average, it considers a normal distribution of the Pareto solutions reducing the influence of solutions allocated at the extremes of the Pareto front.

For computing a solution based on dominance conditions, the criteria solutions expressed in equation (3a) is used. The level of dominance for each of the involved stakeholders is expressed as a weight $(\Phi, 0 \le \Phi \le 1)$. The expressions (4)–(5) are reformulated, using a pondered value (α^P) for the different objectives instead of an average approximation, to obtain:

$$\sum_{j=1}^{J} \Phi_j = 1 \tag{6}$$

$$\alpha_i^P = \sum_{j=1}^{J} \Phi_j \alpha_{i,j} \tag{7a}$$

$$DS = \min \sum_{j=1}^{J} \left| \alpha_i - \alpha_i^P \right| \tag{7b}$$

The stakeholder with the highest ponderation (Φ) is the predominant stakeholder. In addition, different weights can be assigned to the rest of the stakeholders. In this way, a solution is obtained based on dominance (DS), prioritizing the criteria of a dominant participant and taking into account the criteria of the rest of the participants. This solution (DS) reduces the sacrifice of the dominant stakeholder compared with the compromise solution (*CS*).

The solution obtained, considering the level of dominance of the stakeholders (*DS*), can be used to contrast the solution under equality conditions (*CS*) and the criteria of the different stakeholders (*Cr*). It provides a framework for discussing the effects of different criteria over the design and operation of energy systems. In addition, the contrast among the solutions can promote dialogue and an eventual consensus between the participants in the multi-criteria decision environment.

It is important to remark on the assumptions about the proposed geometric approach: It is considered that all the α values associated to the objective functions follow a normal distribution behavior. As a consequence, the solution obtained is strongly influenced by the individual solutions near the central trend measurement. Values about regions at the extremes of the Pareto set have less influence because of the distribution used in this approach. However, the designer, considering the behavior of the data and solutions can use a different distribution approach with statistical criteria for addressing the specific conditions of the weighted average [42].

Typical multi-objective approaches explore the behavior of the Pareto front, including efficient and dominant Pareto optimal solutions. However, these solutions often present gaps between the preferences of the stakeholders [41]. The objective of the proposed strategy is to identify solutions that match the criteria of each stakeholder. Different from typical multi-objective approaches, this strategy avoids exploring the behavior of the Pareto front and focuses on specific solutions based on preferences of the participants in the multi-criteria decision-making environment [43].

2.2.1. *Defining the dominance of stakeholders in a decision-making environment*

The proposed multi-objective optimization strategy considers multiple stakeholders, each one with different levels of preference about the objective functions. These preferences are addressed using a weighting method. The objective is to propose a decision-making framework in which one or more objectives are in conflict, and for which different decision-makers present a proposal that arises from assigning weights to each objective according to their priorities.

Using optimization strategies for conflict resolution, allows reaching a compromise solution and achieving a trade-off among the multiple criteria of the different stakeholders involved in the decision-making environment [35]. This compromise solution is computed considering that all the participants in the decision-making environment have the same importance and influence in the final decision on the design and operation of the energy system [44]. Thus, a condition of equilibrium or equality between all the participants is assumed. Therefore, the formulations for compromise solutions are linked to equality assumptions, which represent an idealized condition. This equality assumption has been used to address general economic problems [45] and specifically, problems associated with the operation of energy systems [46].

However, it is important to consider the dominance relationships in conflict resolutions. The imbalance of influence among the participants depends on the context of the decision-making environment. In an environment where the social power relationships are defined by the level of economic participation, the investors can be considered the dominant participants based on the level of their financial contribution to the energy project [47]. In contrast, projects oriented toward social development are defined by the priorities of the communities linked to the implementation of the energy system [48]. On the other hand, it is important to take into account the complexity for defining a dominance framework and the relationships involved in the decision-making environment. Territorial conflicts generate domination based on land occupied by communities [49]. Alliances and deal-making between entrepreneurs generate dominance criteria based on economic gain or presence in specific markets [50]. Social participation generates domination when several communities generate consensus around common interests [51]. Therefore, defining dominance in decision-making environments is a multi-disciplinary research area where energy-system designers need to collaborate with experts in social sciences to determine imbalances in political power [52]. In this way, it is possible to obtain a suitable solution for reaching a consensus based on the dominance of the different actors.

In this work, the formulation is based on a weighting method for defining a pondering framework to identify a solution for a dominant stakeholder (*DS*) based on the levels of preference of the dominant stakeholder. This solution can be used for reaching a consensus among the participants. In addition, a compromise solution (*CS*) based on the traditional equality assumption is also computed. The contrast between these two solutions provides valuable information:

- From the point of view of the dominant stakeholder, it provides a reference for defining the levels of sacrifice between the solution associated with the criteria of the stakeholder (*Cr*) and the compromise solution (*CS*), computed under the equality assumption. Because the solution obtained considering dominance conditions (*DS*) considers the criteria solution of all the stakeholders, it can be identified as a limit for defining a final decision on the design and operation of the energy system.
- From the point of view of the designer, *DS* indicates the limit of tolerance, based on the attitudes of the dominant stakeholder. This solution can be used as a reference to anticipate conflicts as well as to propose conflict resolution prioritizing the interest of the dominant stakeholder.

For case study, the owners of the hotels are the stakeholders whose priority is the economic objective. However, minor investors involved in the decision-making process could support the development of the proposed technology prioritizing the economic profit and reducing the environmental impact. The government entities, to reduce the consumption of fossil fuels and reduce greenhouse gas emissions, support the implementation of low-carbon technologies, such as SWAC systems. However, in developing countries, local utility companies are operated by government entities, which are interested in obtaining income from the energy consumed from the grid. Government tourism entities, with the purpose of promoting sustainable tourism, can partially invest in the implementation of clean technologies without leaving behind the economic aspect. Therefore, they seek to obtain solutions that are a compromise between the environmental and economic goals. Social organizations, in a decision-making framework, have preferences to obtain solutions with the minimum environmental impact. Finally, the environmental government entity, as a regulator of the environmental impact, represents stakeholders whose criteria lead to prioritization of environmental objectives [53]. They opt for the implementation and operation of a SWAC system, and they are willing to invest large amounts of capital and aiming to reduce greenhouse gas emissions. The stakeholder decision-making framework is presented in Fig. 2.

2.3. *Multi-objective optimization model*

The problem is stated as a multi-objective optimization formulation and is given in the next sub-sections: mass and energy balances, biocide and neutralization chemical dosing, technical constraints, cost and emissions calculation, and objective functions. Each model component is detailed below.

2.3.1. Mass balances

The mass balance is carried out in the treatment plant, where the seawater taken from the ocean (S_t^{ocean}) will be the treated seawater in the plant (S_t^{trat}); it will also be equal to the seawater flowrate that will be distributed to each hotel k in time t ($S_{k,t}$).

$$S_t^{ocean} = S_t^{trat} = \sum_k S_{k,t} \quad \forall t \in T \tag{8}$$

It is assumed that there is no loss of seawater. Therefore, the seawater entering hotel k at a certain time t ($S_{k,t}$) is equal to the seawater leaving the same hotel k at the time t ($S_{k,t}^{out}$). The seawater leaving the hotel is also equal to the flowrate that will be neutralized in the treatment plant (S_t^{neut}).

$$S_{k,t} = S_{k,t}^{out} = S_t^{neut} \qquad \forall t \in T \quad \forall k \in K \tag{9}$$

2.3.2. Energy balances

The energy consumption per hotel k in time t from the use of air conditioning ($\mathrm{econsm}_{k,t}$) as well as the coefficient of performance (COP) are necessary to determine the heat load to be removed from the hotel rooms. Then, the required heat load to be removed from the air in hotel k in time t is ($\mathrm{Q}_{k,t}^{HR}$) is given as:

$$\mathrm{Q}_{k,t}^{HR} = \mathrm{COP} \cdot \mathrm{econsm}_{k,t} \quad \forall t \in T, \forall k \in K \tag{10}$$

This way, it can be supplied using a conventional AC system ($Q_{k,t}^{swac}$) or a SWAC system ($Q_{k,t}^{water}$).

$$\mathrm{Q}_{k,t}^{HR} = Q_{k,t}^{swac} + Q_{k,t}^{ac} \quad \forall t \in T, \forall k \in K \tag{11}$$

The coefficient of performance of the conventional AC systems in time t is required ($COP_{k,t}^{ac}$). This term is defined as the ratio between the heat removed from the hot source in hotel k in time t ($Q_{k,t}^{ac}$) and the work required by a conventional AC system ($Elect_{k,t}^{ac}$) [54].

$$COP_{k,t}^{ac} = \frac{Q_{k,t}^{ac}}{Elect_{k,t}^{ac}} \quad \forall k \in K, \forall t \in T \tag{12}$$

It should be noted that $\mathrm{COP}_{k,t}^{ac}$ is not constant and depends on several factors. However, some of these factors are stochastic, such as the partial load ratio in time t ($PL_{k,t}^{ac}$), which is the ratio between the heat removed from the hot source in hotel k in time t ($Q_{k,t}^{ac}$) and the maximum design heat (Q_k^{emax}). It is calculated as follows:

$$PL_{k,t}^{ac} = \frac{Q_{k,t}^{ac}}{Q_k^{emax}} \quad \forall k \in K, \forall t \in T \tag{13}$$

A conventional AC system operating at partial load also causes its motor to operate less effectively because the efficiency of an electric motor decreases when the operating point is lower than its rated power.

Therefore, the COP is a function of the partial load, $\mathrm{COP}_{k,t} = f(\mathrm{PL}_{k,t})$ and they are related in the following way:

$$\mathrm{COP}_{k,t}^{ac} = \mathrm{T1}\left(PL_{k,t}^{ac}\right)^2 + \mathrm{T2}\left(PL_{k,t}^{ac}\right) - \mathrm{T3} \qquad \forall k \in K, \forall t \in T \tag{14}$$

Thus, to know how much seawater ($S_{k,t}$) is required to remove this heat in each hotel k in time t ($Q_{k,t}^{swac}$) an energy balance is required.

$$Q_{k,t}^{swac} = S_{k,t} \rho \mathrm{Cp}^{sw} \Delta \mathrm{T} \quad \forall t \in T, \forall k \in K \tag{15}$$

where the physical proprieties of the seawater are density (ρ), calorific capacity (Cp^{sw}), and temperature difference (ΔT).

2.3.3. Biocide and neutralization chemical dosing

Using seawater as a cooling medium comes with problems such as corrosion and biofouling of equipment that is in direct contact with seawater, and these can shorten the lifespan and reduce the thermal efficiency of the equipment. Thus, a biocide is needed (F_t^{bio}) with a certain concentration to exhibit a biocidal effect (C^{bio}). To achieve this concentration, the commercial biocide concentration (C_t^{in}) is that which is required to treat the seawater in the treatment plant (S_t^{ocean}):

$$F_t^{bio} = \frac{\mathrm{C}^{bio} S_t^{ocean}}{\mathrm{C}^{in}} \quad \forall t \in T \tag{16}$$

To carry out the neutralization, the chemical flowrate (F_t^{chem}) depends on the initial flowrate of the seawater stream to be neutralized (S_t^{neut}), as well as the initial concentration of the biocide and of the neutralization chemical.

$$F_t^{chem} = \frac{\mathrm{C}^{in} S_t^{neut}}{\mathrm{C}_{bio}} \quad \forall t \in T \tag{17}$$

It should be noted that the ratio must be 1:1 in order to ensure complete dechlorination.

2.3.4. Technical constraints

Equipment sizing is a very important aspect that must be considered in cost estimation. For this purpose, the maximum capacity should be considered at all times. Therefore, the following restrictions are required:

The heat exchanger size required by hotel k is determined by the maximum heat load removed with seawater, which must be higher than the maximum heat removed at any time t (Q_k^{qwm}).

$$Q_k^{qwm} \geq Q_{k,t}^{swac} \qquad \forall t \in T, \ \forall k \in K \tag{18}$$

where y_k^{he} is the binary variable that represents the heat exchanger existence in hotel k in the configuration.

$$Q_k^{qwm} \leq \mathrm{Q}^{max} y_k^{he} \qquad \forall t \in T, \ \forall k \in K \tag{19}$$

On the other hand, y^{trat} is the variable associated with the main pipeline from the deep ocean to the treatment plant. If the binary variable is equal to one, then the pipeline segment exists and its flowrate must be lower than a maximum limit. However, if the binary variable is equal to zero then it does not exist.

$$S_t^{trat} \geq \sum_k S_{k,t} \quad \forall t \in T \tag{20}$$

$$S_t^{trat} \leq \mathrm{S}^{tmax} \cdot y^{trat} \qquad \forall t \in T \tag{21}$$

In the same context, the variable associated with the existence of each segment of pipeline from the treatment plant to each hotel k is (y_k^{hotel}). Here, the flowrate in each segment of the pipeline must be lower than the flowrate in any given time period t and must be lower than a maximum limit.

$$S_k^{max} \geq S_{k,t} \quad \forall k \in K, \forall t \in T \tag{22}$$

$$S_{k,t} \leq S^{hmax} \cdot y_k^{hotel} \quad \forall k \in K \tag{23}$$

The following relationship indicates that if a flowrate in a treatment plant exists, then the flowrate to each hotel and the leaving flowrates also exist. Therefore, this pipeline segment must exist and is designated with the binary variable y_k^{out} .

$$y_k^{hotel} = y_k^{out} \qquad \forall k \in K \tag{24}$$

2.3.5. Economic objective function

This function provides for the minimization of the total annual cost (*TAC*), which involves the costs of heat exchangers (*HeateCost*), pipelines (*PipingCost*), pumps (*PumpCost*), pumping (*PumpingCost*), and electricity (*ElectricityCost*), as well as the costs associated with mechanical maintenance (*MaintCost*), the purchase of chemicals (*ChemicalCost*) and biocide (*BiocideCost*).

$$Min\ TAC = \begin{bmatrix} HeateCost + PipingCost + PumpCost + PumpingCost \\ +ElectricityCost + BiocideCost + ChemicalCost + MaintCost \end{bmatrix} \tag{25}$$

2.3.6. Costs calculations

2.3.6.1. Heat exchangers. The heat exchanger cost depends on the exchange area (A_k) and is associated with the maximum heat load in any time (Q_k^{qwm}). In addition, the logarithmic mean temperature difference (ΔT_{ml}) and the global heat transfer coefficient (U) are required.

$$A_k = \frac{Q_k^{qwm}}{\Delta T_{ml} U} \quad \forall k \in K \tag{26}$$

It is worth mentioning that in order to evaluate heat exchanger performance, the efficiency ($\eta_{k,t}^{HE}$) needs to be calculated. This is the ratio between the real heat transferred in each hotel k in time t ($Q_{k,t}^{swac}$) and the maximum possible heat transfer in each exchanger considered (Q_k^{qwm}).

$$\eta_{k,t}^{HE} = \frac{Q_{k,t}^{swac}}{Q_k^{qwm}} \quad \forall t \in T, \forall k \in K \tag{27}$$

A linear function is used to obtain the heat exchanger unitary cost. $FCost_k^{unit}$ is the fixed cost and is only added if a heat exchanger exists. $VCost_k^{unit}$ is the variable cost and it depends on the installed area. Moreover, y_k^{he} is the binary variable and if it is equal to one, then the heat exchanger exists, and the cost is included. Otherwise, the heat exchanger does not exist and the cost is not considered.

$$Cost_k^{unit} = VCost_k^{unit}(A_k)^{\delta} + FCost_k^{unit} y_k^{he} \quad \forall k \in K \tag{28}$$

Thus, the total capital cost of the heat exchangers that the SWAC system requires is:

$$HeateCost = k_F \sum_k Cost_k^{unit} \tag{29}$$

where (k_F) is an annualization factor.

2.3.6.2. Pipelines. Cost factors (*Pcf*) are used to estimate the cost of associated pipelines. It should be noted that three segments of the pipeline are identified. The first segment corresponds to the pipeline from the deep ocean to the treatment plant (Pcf^{trat}), the second corresponds to pipelines required for distribution (according to the number of the hotels k) (Pcf_k), and the last segment corresponds to the pipelines required to send seawater from hotel k to the neutralization plant (Pcf_k^{out}). Each cost factor is associated with the length (L) and diameter (D^m) of the pipeline. Moreover, k_m and m are cost parameters that depend on the pipeline material.

$$Pcf^{trat} = k_m L D^m \cdot y^{trat} \tag{30}$$

$$Pcf_k = k_m L_k D_k^m \cdot y_k^{hotel} \quad \forall k \in K \tag{31}$$

$$Pcf_k^{out} = k_m L_k D_k^m \cdot y_k^{out} \quad \forall k \in K \tag{32}$$

The cost of each segment is multiplied by its respective binary variable according to the existence or non-existence of the segments that determine its cost.

The total piping cost will be:

$$PipingCost = k_F \left[Pcf^{trat} + \sum_k Pcf_k + \sum_k Pcf_k^{out} \right] \tag{33}$$

2.3.6.3. Pumps. If a segment of pipeline exists, then a pump is required. The cost of the pumps associated with each segment will be:

$$Pcost1 = CVP^{pump} S^{tmax} + CFB^{pump} y^{trat} \tag{34}$$

$$Pcost2_k = CVP_k^{pump} S_k^{max} + CFB_k^{pump} y_k^{hotel} \quad \forall k \in k \tag{35}$$

$$Pcost3_k = CVP_k^{pump} S_k^{max} + CFB_k^{pump} y_k^{out} \quad \forall k \in k \tag{36}$$

where CFB^{pump} and CVP^{pump} are the fixed and variable cost, respectively. In addition, the variable cost depends on the maximum flow in each pipeline segment.

Moreover, the total cost for the pumps will be:

$$PumpCost = k_F \left(\left(\sum_k Pcost2_k + \sum_k Pcost3_k \right) + Pcost1 \right) \tag{37}$$

2.3.6.4. Pumping. The pumping costs are associated with the pumped flowrate of each of the pumps required in each segment, which is multiplied by the operating hours per year ($\mathrm{H_Y}$):

$$PumpingCost = \mathrm{H_Y}\left[\sum_t S_t^{trat}\mathrm{PFC1_t} + \sum_k\sum_t S_{k,t}\mathrm{PFC2_{k,t}} + \sum_k\sum_t S_{k,t}^{o}\mathrm{PFC3_{k,t}}\right] \quad (38)$$

Here $\mathrm{PFC1}_t$, $\mathrm{PFC2_{k,t}}$, and $\mathrm{PFC3_{k,t}}$ are pumping factors that correspond to each segment of the system. These are calculated as follows:

$$\mathrm{PFC} = \frac{1}{0.0000576} f \frac{\mathrm{L}}{D^5} \frac{(\text{no. de hrs})(\mathrm{UCE})}{\eta} \quad (39)$$

These factors are associated with the length (L) and the diameter (D) of the pipeline. In addition, the friction factor (f), the pump efficiency (η), and the unitary electricity cost per hour of operation (UCE) are considered.

2.3.6.5. Electricity. The total electricity cost is associated with the individual electricity cost paid to the public grid for using the conventional AC system in hotel k in time t ($Cost_{k,t}^{e}$). Therefore, the sum of all of them will be the total electricity cost:

$$ElectricityCost = \sum_k\sum_t Cost_{k,t}^{e} \quad (40)$$

The individual cost ($Cost_{k,t}^{e}$) is obtained from the electricity consumption multiplied by the unitary cost per kWh (UCE).

$$Cost_{k,t}^{e} = Elect_{k,t}^{e} \cdot \mathrm{UCE} \quad \forall t \in T,\ \forall k \in K \quad (41)$$

However, to know the total electricity using a conventional AC system ($Elect_{k,t}^{e}$), the heat removed by a conventional AC system ($Q_{k,t}^{ac}$) and the $\mathrm{COP}_{k,t}^{ac}$ for each hotel k in time t are required.

$$Elect_{k,t}^{e} = \frac{Q_{k,t}^{ac}}{\mathrm{COP}_{k,t}^{ac}} \quad \forall t \in T,\ \forall k \in K \quad (42)$$

2.3.6.6. Biocide and neutralization chemical. The biocide and neutralization chemical costs are associated with the flowrate required.

$$BiocideCost = \sum_t F_t^{bio}\xi \quad \forall k \in K,\ \forall t \in T \quad (43)$$

$$ChemicalCost = \sum_t F_t^{chem}\gamma \quad \forall k \in K,\ \forall t \in T \quad (44)$$

where ξ and γ are the unitary costs of these utilities.

2.3.6.7. Mechanical maintenance. A number of planned maintenance operations per year must be carried out to clean the equipment; this improves their efficiency. Therefore, the cost associated with this concept is:

$$MaintCost = \beta\tau y^{main} \quad \forall k \in K \quad (45)$$

Here, τ is the number of programmed maintenance events per year and β is the unitary cost per maintenance. The binary variable y^{main} indicates that maintenance is required; it is also associated with the existence or absence of heat exchangers, if at least one heat exchanger exists then maintenance must be scheduled during the year.

$$y_k^{he} \le y^{main} \quad (46)$$

2.3.7. Environmental objective function

The other objective function corresponds to the environment and it provides for the minimization of total greenhouse gas emissions (*GHGE*). Thus, this function can be expressed as a function of the emissions produced for each type of cooling system: by the SWAC system (*GhgeSwac*) and the conventional AC system (*Ghgelect*).

$$Min\ GHGE = [GhgeSwac + Ghgelect] \quad (47)$$

2.3.8. Emissions calculation

The environmental impact will be measured through global CO_2 emissions, which can be generated by both systems.

2.3.8.1. Conventional air-conditioning system emissions. In this case, the emissions will be evaluated according to the amount of electricity expended for each hotel k in time t ($Elect_{k,t}^{e}$). A direct emissions factor ($\phi_{\ GHGE}$) of 0.582 kg, CO_2/kWh is used [55].

$$Emelec_{k,t} = Elect_{k,t}^{e} \cdot \phi_{GHGE} \qquad \forall k \in K,\ \forall t \in T \quad (48)$$

Therefore, the total emissions per year will be the sum over time of the emission generated by all the hotels:

$$Ghgelect = \sum_k\sum_t Emelec_{k,t} \quad (49)$$

2.3.8.2. Seawater air-conditioning system emissions. With a SWAC system, the CO_2 emissions are generated by the pumps that the system requires because they operate on electrical energy. A linear function that relates power to flowrate is used, wherein $\Omega_{\mathrm{i,t}}$ and $\Psi_{\mathrm{i,t}}$ are the slope and intercept in the linear regression obtained for each pump.

$$Power_t = \Omega_{\mathrm{t}} \cdot S_t^{ocean} + \Psi_{\mathrm{t}} \cdot y^{trat} \quad \forall t \in T \quad (50)$$

$$Power2_{k,t} = \Omega_{\mathrm{k,t}} \cdot S_{k,t} + \Psi_{\mathrm{k,t}} \cdot y_k^{hotel} \quad \forall k \in K, \forall t \in T \quad (51)$$

$$Power3_{k,t} = \Omega_{\mathrm{k,t}} \cdot S_{k,t}^{out} + \Psi_{\mathrm{k,t}} \cdot y_k^{out} \quad \forall k \in K,\ \forall t \in T \quad (52)$$

Then, the total power in all the times is:

$$TotalPower = \sum_k\sum_t Power2_{k,t} + \sum_k\sum_t Power3_{k,t} + Power_t \quad (53)$$

The total energy consumed by the system pumps (*EnergyPump*) is calculated by multiplying the total power by the operating hours (H_Y):

$$EnergyPump = TotalPower \cdot H_Y \tag{54}$$

The emissions generated by the SWAC system are calculated using the same factor as that in equation (48):

$$GhgeSwac = EnergyPump \cdot \phi_{GHGE} \tag{55}$$

3. Results and discussion

The proposed MINLP model was coded in the modeling language GAMS. The solver Baron was used to solve the model [56]. The model was solved using the weighting method to obtain the Pareto front to address the conflicting priorities among multiple stakeholders and was measured by how satisfied/dissatisfied stakeholders were with a given decision with respect to the utopia and nadir points [41]. Each point represents a criterion, a different configuration and operation policy on the system (See Fig. 4). The results are presented considering three different criteria according to the point of view of the predominant stakeholder. The first case shows the individual interest of the dominant stakeholder and all the rest in the systems design. The second case shows the difference between individual interests and the compromise solution obtained assuming that all the stakeholders have the same level of importance in the decision-making framework. Finally, a pondered compromise solution where all the stakeholders are included considering their specific level of participation in the final decision and identifying the dominant stakeholder with the highest weight in the system configuration is shown in the third case.

3.1. Case 1. set of individual solutions

Table 1 shows the comparison between the different criteria according to the stakeholder priorities. The impact was evaluated through the weight assigned to each objective. Moreover, those assigned weights have an impact on the configuration and operation policy of the SWAC system, as well as the conventional AC system operation policy. In this case, different weights were assigned for the economic (ω_1) and environmental (ω_2) objectives. The utopia point represents the desired values of the considered objective functions. This point had a total cost of $317,720 with emission generation of 214 t CO_2 eq./year. This is compared with the nadir point, which has a total cost of $1,556,100 and 1143 t CO_2 eq./year and represents the undesired values of the objective functions. It should be noted that both points are infeasible, because they are outside of the feasible region.

Nevertheless, in this decision-making framework, the dominant stakeholder will always be the one who supports the economic objective, looking for the greatest economic benefit. This criterion corresponds to stakeholder 1 in Table 1, who seeks the minimum TAC, in this case, a value of $317,720/year. This corresponds to the electricity purchase from the public grid; however, it represents the worst environmental proposal because there is a generation of 1143 t CO_2 eq./year. In the emissions case, by minimizing the TAC, the emissions increase by 81% compared to the case where GHGE is minimized. This proposal presents environmental and economic disadvantages: large amounts of electricity must be purchased from the public grid to supply air-conditioning utilities through the conventional AC system operation, and the proposed technology is not used. Consequently CO_2 emissions are high (see Table 2). The total electricity required by the hotel network is 1,674,750 kWh/year. For the 5-star hotels category, hotel H51 is the biggest and requires 583,110 kWh/year, while the smallest (hotel H51) requires 436,200 kWh/year. For the 4-star hotels category, the hotel H41 is the biggest and requires 352,580 kWh/year, while the smallest (hotel H42), with low electricity needs, requires 302,860 kWh/year.

The criteria of stakeholders (2–6) are defined by solutions with different levels of prioritization between cost and emission adjustments. In this case, hotels are operating under a combination of both systems. For stakeholders 2 and 3, different weights are assigned prioritizing the economic objective; furthermore, in both cases, the environmental aspect already has some weight in decision-making. TAC was increased while the weight was reduced, but the GHGE decreased as more participation in decision-making was considered. The TAC increased 155% and 186%, while GHGE decreased 14% and 28% respectively. The stakeholder 4 criterion represents an equilibrium solution because both objective functions have the same weight, with 50% each in decision-making. There was a TAC of $1,095,200/year and a total GHGE of 585 t CO_2 eq./year, reducing total annual emissions by 49%, with respect to the nadir point. For stakeholders 5–6, different weights were assigned, for which in both cases the environmental aspect was prioritized. In this case, the TAC increased significantly to $ 1,286,200/year and $1,534,500/year and the GHGE was 524 t of CO_2

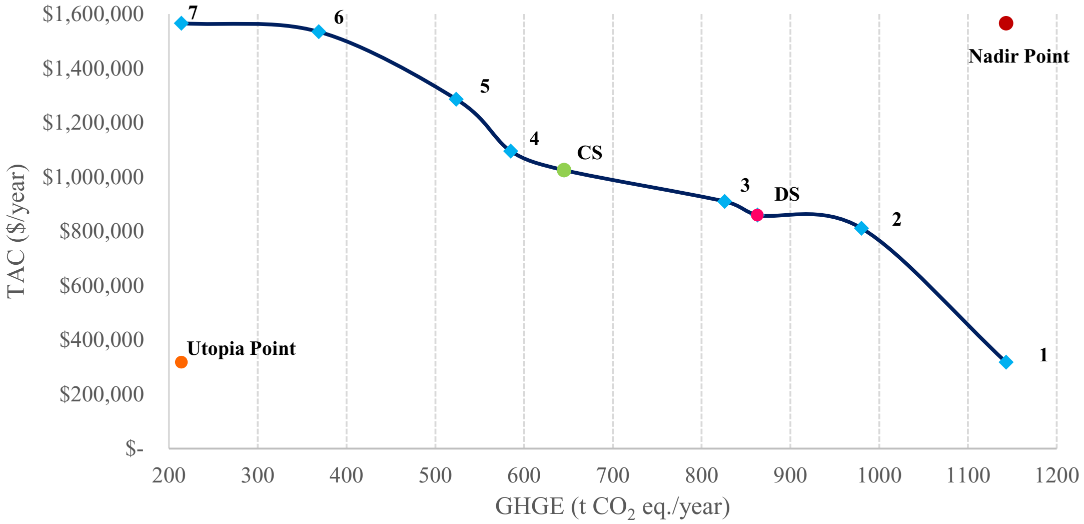

Fig. 4. Pareto front.

Table 1
Set of individual solution.

Stakeholder	Weights						Objectives	
	ω_1 TAC	ω_2 GHGE	Φ	$\alpha1$	$\alpha2$	Crj	TAC ($/year)	GHGE (t CO_2 eq./year)
1	1	0	0.5	0	1	0	317,720	1143
2	0.8	0.2	0.06	0.244	0.780	0.321	811,410	980
3	0.6	0.4	0.06	0.454	0.565	0.495	910,140	826
4	0.5	0.5	0.06	0.648	0.464	0.556	1,095,200	585
5	0.4	0.6	0.06	0.928	0.085	0.422	1,286,200	524
6	0.2	0.8	0.06	0.960	0.100	0.216	1,534,500	369
7	0	1	0.2	1	0	0	1,566,100	214
Utopia Point							317,720	214
Nadir Point							1,566,100	1143

Table 2
Electricity requirements of stakeholder 1 proposal.

Hotel	Electricity (kWh/year)
H51	583,110
H52	436,200
H41	352,580
H42	302,860

eq./year and 369 t of CO2 eq./year, respectively. The emissions decreased 54% and 68% for both scenarios, with respect to the worst case. The stakeholder 7 criterion represents the SWAC system implementation and operation without the requirement for a conventional AC system. As result, the minimum GHGE and the maximum TAC are obtained.

All the criteria represent different solutions according to the weight they give to each objective. However, a consensus must be reached considering all these criteria as well as the dominant stakeholder criterion in the decision-making framework because the dominant stakeholder has the last word in the development of new technologies.

3.2. Case 2. compromise solution under the equality assumption

The objectives are usually conflicting and therefore, the solution is highly dependent on the preferences of the decision-maker. However, the aim is to minimize the dissatisfaction of the stakeholders through a compromise solution (see Eq. (5)). In this case, all the stakeholders have the same level of importance and participation and the goal is to improve economic and environmental performance (see Table 3).

This proposal, compared with the stakeholder 1 proposal, represents an increase of 2.23 times in TAC with a value of $1,025,100/year, with respect to GHGE of 645 t of CO_2 eq./year, reducing the total annual emissions by 44%.

The analysis of this solution presents a trade-off between the environmental and economic objective. In this case, two hotels are using deep seawater, that is, a specific design and different operating conditions of the SWAC system is required (seawater, biocide, neutralization chemical, and energy requirements, as well as heat exchanger size). The other two hotels are using electricity to run their conventional AC systems. The SWAC system requires 329,670 m^3/year of seawater, which is distributed according to the daily cooling requirements in each hotel. This configuration requires 329 m^3/year of biocide to maintain the heat transfer through the heat exchangers at a desirable level and 329 m^3/year of neutralization chemicals in order to neutralize the biocide fully. With this configuration, 766,182 kWh/year from the public grid is needed to cover the air conditioning utilities for the four hotels, that is to say, 908,568 kWh/year of electricity less than that of the proposal of stakeholder 1. In the long term, this can lead to significant savings due to the renewable energy concept and in this way reduce the amount of emissions to the environment. Water and energy requirements, as well the heat exchanger size in each hotel, are given in Table 4.

Table 3
Compromise solution, minimizing the dissatisfaction.

α_1	α_2	**CS**	Objectives **TAC ($/year)**	GHGE (t CO_2 eq./year)
0.632	0.388	1.096	$1,025,100	645

The implementation of this solution could be undesirable from the point of view of the dominant stakeholder because of the evident conflict with the economic result. Considering the global preferences of the stakeholders, this solution is acceptable for reaching a consensus between the multiple criteria involved in the decision process. However, owing to the imbalance associated with the influence of the dominant stakeholder and its interest and priorities, this solution can be discarded. As described previously, hotel owners provide the main source of funding for this project; as a consequence, they want to increase the economic profit of the new facilities by reducing their own financial sacrifice.

3.3. Case 3. consensus considering a dominant stakeholder

Each stakeholder brings along different criteria and points of view that must be resolved within a framework of mutual compromise. The last criterion represents a consensus between all stakeholders involved, obtaining a pondered compromise solution considering a dominant stakeholder with the highest weight on the final decision. The new ponderation is established according to the weight of each stakeholder in the decision-making framework. The dominant participant with greater weight in decision-making focuses on the economic objective ($\Phi = 0.5$) because it presents the stakeholder with the best investment. In addition, the stakeholder with environmental priority ($\Phi = 0.2$) must be considered for the design to be a sustainable process and has the second highest weight in this decision-making framework. The rest of the stakeholders with less participation should be considered with an even lower weight ($\Phi = 0.06$) because the participation of all stakeholders involved in the decision making is required in order to reach a consensus.

This solution represents the use of both cooling systems, where hotel H51 operates under the proposed technology (SWAC system) and the other three hotels operate under conventional AC systems to achieve environmental and economic objectives that satisfy all stakeholders. With a value of $859,550/year, an increase in the TAC

Table 4
Compromise solution under equality assumption proposal.

Hotel	Seawater flow (m^3/year)	Electricity (kWh/year)	Heat exchanger size (m^2)
H51	204,170	23,715	**43**
H52	–	436,200	**-**
H41	125,500	3,407	**26**
H42	–	302,860	**-**
Biocide flow(m^3/year)	329	**Chemical Flow(m^3/year)**	329

Table 5
Dominant stakeholder proposal.

Hotel	Seawater flow (m^3/year)	Electricity (kWh/year)	Heat exchanger size (m^2)
H51	173,710	68,735	**39**
H52	–	436,200	**-**
H41	**-**	352,580	**-**
H42	–	302,860	**-**
Biocide Flow(m^3/year)	174	**Chemical Flow(m^3/year)**	174

of 171% compared to the stakeholder 1 proposal, and 16% less than with the compromise solution. With respect to GHGE, 863 t of CO_2 eq./year are produced, reducing the total annual emissions by 24% compared with the stakeholder 1 proposal and 34% more than the compromise solution. The SWAC system requires a heat exchanger with 39 m^2 of area. In addition, 173,710 m^3/year of seawater are required to supply the daily cooling of hotel H51, which when compared with the compromise solution, requires 155,960 m^3/year less. This configuration requires 174 m^3/year of biocide to maintain the heat transfer through the heat exchangers at a desirable level and 174 m^3/year of neutralization chemical in order fully neutralize the biocide. The rest of the hotels operate using conventional AC systems that require 1,160,375 kWh/year of electricity from the public grid (i.e., 31% less than with the stakeholder 1 proposal). Compared with the compromise solution, significantly more electricity (394,193 kWh/year) is required. The water and energy requirements of each hotel for this configuration are given in Table 5.

In contrast with the solution presented as Case 2, this solution reduces the costs of implementing the new facilities, compared with the rest of the solutions. The main contribution of this solution to the discussion framework is consideration of significant economic sacrifice to implement the new energy facilities. The dominant stakeholder could accept a maximal level of sacrifice to reach a trade-off between the preferences of all the stakeholders. As a consequence, this solution can be assumed to be the acceptable limit for increasing the cost of the system considering a substantial mitigation of environmental impact and considering the criteria of other stakeholders.

It is important to highlight the role of the dominant stakeholder, which represents a duality in the decision-making process. First, the criteria for this role are determinant for defining the final configuration of the system. The equality considerations presented in previous studies provided a reductive analysis because they considered that all stakeholders had similar opportunity to influence the final decision on the system. However, as presented in Case 2, this assumption is not the most desirable solution when the preferences of the dominant stakeholder are allocated near the extremes of the Pareto solutions. Consequently, the use of the solution based on equality can lead to the rejection of the project by prioritizing the use of conventional systems or, in the best case, a search for different technological configurations, thereby delaying progress and new development of the facilities.

On the other hand, the dominant stakeholder could sacrifice most preferences and provide a limit for the development of new technologies according to its interest in new energy projects and facilities. In this sense, the proposed strategy could be a useful tool for identifying the limits in the multi-criteria decision-making environment. All the stakeholders can identify the effect and consequences of their preferences in the solutions and reduce their levels of interest in different aspects of the design. This would be motivated by considering that the implementation of technologies is delimited by the interest and willingness to yield or change priorities by the dominant stakeholder. In this way, the stakeholder is not just a delimiter, but also an active generator of solutions and proposals, thereby showing a level of flexibility for accelerating the discussion about new energy projects.

4. Conclusions and future work

A framework for managing conflicts in a multi-criteria decision-making environment has been presented. The multi-objective optimization modeling used, considers the differences between a compromise solution (CS) based on equality assumptions and a solution based on the level of influence (DS), or dominance, of the different stakeholders involved in the decision-making environment.

The dominant stakeholder is identified as the participant with the highest influence and importance in the decision-making process. Therefore, the computed solution based on dominance (DS) reduces the levels of sacrifice in the priorities of the dominant stakeholder over the objective functions.

For exploring the differences between the compromise solution, obtained under equality assumptions, and the solution considering the level of dominance of the different stakeholders, a multi-objective optimization model has been presented for the design of a seawater air conditioning system (SWAC) for a tourism complex. The dominant stakeholder is defined based on the level of economic participation. Therefore, the dominant stakeholders are the investors and owners of the hotels. Consequently, their priorities are based on the economic priorities of the participants.

The proposed strategy allows the definition of specific Pareto optimal solutions that match with the criteria of the stakeholders. These criteria are expressed using weights over the objective functions. In addition, the level of dominance of each stakeholder is defined by weights that are used for obtaining a pondered value of the objective function. It is important to remark on the complexity to define the level of dominance of a participant in the decision-making environment. This leads to consideration of a multidisciplinary approach for determining in a suitable way the weights used to define the levels of dominance.

The results obtained show a significant difference between the typical approach used in the current literature, considering an equality assumption that leads to an equilibrium solution near the average values of preferences about objective functions, and the solution under conditions considering dominance. Prioritizing the preferences of the dominant stakeholder leads to computation of the nearest Pareto optimal solution to the criteria solution of the dominant stakeholder, and to reaching of a trade-off among the criteria of the rest of the participants. For addressed case study, the dominant stakeholder has a preference over the economic profit of the project. Consequently, the solution under dominance conditions is allocated in a Pareto region near to the economic extreme of the Pareto front. However, the influence of the stakeholders with environmental priorities (minimizing CO_2 emissions) leads to reducing the economic profit relative to the economic profit reached by a solution based on the preferences of the dominant stakeholder.

Therefore, the proposed strategy has significant application for solving conflicts in multi-criteria decision environments. For future work, it is important to consider and induce modeling of the social concepts of power imbalance and force correlation to consider the association and alliances among multiple participants. In addition, it is possible to establish a suitable framework for defining the weights for dominance conditions.

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