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Alternatives for domestic water tariff policy in the municipality of Chania, Greece, toward water saving using game theory

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Abstract

As defined in the EU Water Framework Directive, every water tariff policy should be fair toward customers, generate legitimate revenue, and motivate consumers toward water saving. In the city of Chania, Greece, the inhabitants have asked for a fairer tariff policy and exhibited the intention to save water under the implementation of stricter measures. Therefore, a two-person zero-sum game was proposed, involving a conflict of interest between the Municipal Enterprise for Water and Sewage of Chania (MEWS) (Player 1) and the city's approximately 108,000 residents (Player 2). Three scenarios for the gradual reduction of the fixed charges and the gradual increase of volumetric charges were developed, assuming a different degree of change in water consumption behavior by each consumption block of consumers. The payoff matrices, for each scenario, incorporated two clear cost strategies for Player 1, in terms of changing the current tariff policy, and four clear cost strategies for Player 2, regarding the change in consumers' behavior. The optimal decision for both players, derived from the identification of the equilibrium point, demonstrated that domestic water consumption may be reduced by up to 4.6% while maintaining the MEWS's profit. The proposed model can provide a guide for other similar applications.

Keywords: Game theory; Municipal water; Tariff policy; Water consumption; Water saving

Introduction

According to the United Nations (2006), the global population, while currently at 6.5×10^9, is expected to exceed 9×10^9 by 2050. This profound growth rate is to impose a significant increase in water and food demand (Ragab *et al.*, 2015), while at the same time, water resources are under threat due to mismanagement and climate change (Vörösmarty *et al.*, 2000; Vrochidou *et al.*, 2013). In light of this, governments and intergovernmental panels must take action to ensure that there are enough natural resources to sustain these rates of growth as well as ensure the current welfare.

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Much research has been conducted concerning the tariff policy of irrigation water (Perez-Blanco *et al*., 2015; Podimata & Yannopoulos, 2015), since it accounts for more than 70% of total water use (Food and Agriculture Organization of the United Nations (FAO), 2002), especially in arid regions such as those of the Mediterranean Basin. On the contrary, only a few studies have dealt with the domestic water-charging systems using decision-making tools. Nevertheless, sustainable domestic water tariff policy management is necessary, as it aims to ensure both water resource protection and socioeconomic advances. This is in line with the EU Water Framework Directive (European Parliament, 2000), which suggests that the structure of the tariff policy must motivate citizens to save water and rationalize its use. In the City of Chania, the domestic water consumption policy does not follow this direction. In contrast, the tariff policy is mainly based on fixed charges, while the volumetric consumption charges are underestimated. Thus, this kind of policy does not motivate citizens toward water saving.

Domestic water tariff policies generally differ considerably among cities and counties and depend on water availability, available infrastructure, socioeconomic factors, the legal state of water in each county, and the standard of living (Pinto & Marques, 2015). In their work, Pinto & Marques (2015) presented an extensive review of different tariff policies in different cities of the world. The major observation from this work was that different tariff policies could be found in financially diverse communities. According to the European Environment Agency (EEA, 2013), the level of the tariff should be determined using a cost-based approach regarding utility costs and consumer demands. Tsagarakis (2005) presented a tariff structure that considers different components that affect the tariff level: (a) a fixed charge component, (b) a volumetric component, (c) an adjustment component, and (d) other charges. The latter two are applied to adapt to the local characteristics of each case study.

Many studies have assessed the variable tariff policies and their potential effects in the diverse communities of the world. A recent work presented insights of the tariff policies in India and China. Both countries are working on domestic water tariff policies to rely on cost recovery through user fees. There is considerable variation among cities with those in water-short areas charging more than those with abundant water resources. However, this work concludes that in contrast to fixed charges or state subsidy policies, a water tariff policy that relies on volumetric consumption promotes water conservation (Lee *et al*., 2016) and reduces discrepancies between low and high consumers. A uniform water price increase was applied in Manaus, Brazil to all users, causing variable effects on the different categories of residents. It significantly affected the poorest households who were billed on a fixed basis, experiencing an increase of 35% in their water bills (Olivier, 2010). In Portugal, a study of domestic water tariff policies at the country scale under conditions of cost recovery found that it is more expensive to supply water services to rural populations who often have lower incomes than urban populations, leading to increased charges for the populations of rural areas (Egerton *et al*., 2011).

Game theory deals with interactive situations where two or more individuals, called players, make decisions that jointly determine the final outcome (Bonanno, 2015). The discipline of game theory was pioneered by mathematicians Zermelo (1913) and von Neumann (1928). Since the important work of Nash (1950) and Shapley (1953), game theory has had a major influence on the development of several branches of economics, social sciences, and other fields. Game theory considers mathematical models of conflict and cooperation between intelligent and rational decision-makers. There must be two or more players, each of whom aims to gain advantage over the opponent(s). Thus, each player's actions depend on the opponent's chosen strategies in order to maximize one's profit or minimize one's loss. When a game is presented in normal form, it is presumed that each player acts simultaneously or, at least, without knowing the actions of the other. If players have some information about the choices of the other players, the game is usually presented in extensive form.

Specifically, in the area of water resources, it has been applied in many disciplines. In Dinar & Hogarth (2015), a critical review of game theory applications in water resources was performed, assessing many disciplines. Madani (2010) reviewed a series of non-cooperative game theory practices in water resources management. In water supply and sanitation projects (Amit & Ramachandran, 2010), non-cooperative game theory was applied in a two-period game between the public agent sector and users to achieve a fair and economically efficient management plan. Varouchakis *et al*. (2016) examined the applications of scaled financial penalties to irrigators for over-pumping compared to the construction of an irrigation dam. Wei *et al*. (2010) applied game theory-based models to analyze water allocation in the Middle Route of the South-to-North Water Transfer Project in China. They found that the unwillingness of the players to cooperate leads to a prisoners' dilemma game. Getirana & de Fátima Malta (2010) applied a graph model of a non-cooperative game under six management scenarios to the irrigators of a major canal in Brazil. They also allowed external intervention from the public agent to suggest a preferable solution to the conflict. Loáiciga (2004) assessed cooperative and non-cooperative games in groundwater management, showing that water use is beneficial in terms of sustainability using a cooperative arrangement. Salazar *et al*. (2007) presented a series of cooperative solutions under game theory principles to connect the financial benefit of the farmers and the reduction of the environmental risk of aquifer management, which is the payoff of the community. Zadeh *et al*. (2009) applied non-cooperative and cooperative game theory to examine the conflict of two municipalities and one agricultural agent in the management of rural water. It was suggested that cooperation yields higher benefits compared to non-cooperation scenarios. Madani & Lund (2012) explained that the delta problem of the State of California (i.e., whether and how to transfer water from the bay/delta to users elsewhere in the state) is of a prisoners' dilemma nature. Thus, stakeholder self-interest makes cooperation unlikely within a reasonable time frame. However, because of the unsustainable water resources, the problem has characteristics of a chicken game, where cooperation is in everyone's interest.

Stochastic game theory has also been applied in transboundary river water sharing (Just & Netanyahu, 2012). The bankruptcy concept was applied under water scarcity and uncertainty conditions to provide water allocations that are self-enforced under the equal awards rule in the Nile River Basin among the countries of Ethiopia, Soudan, and Egypt (Degefu *et al*., 2016). Another application of game theory was on the sharing of the Mountain Aquifer between Israel and Palestine. Netanyahu *et al*. (1998), using both cooperative and non-cooperative bargaining game theory, suggested that game theory approaches are robust concerning demand elasticity, user costs, and pumping costs. The Nash bargaining solution to a real water allocation problem was considered in the Mexican Valley in Mexico, one of the most critically water-scarce regions in the state (Salazar *et al*., 2010). The authors developed a three-player non-symmetric Nash bargaining model that solved an optimization problem with a non-linear objective function and linear constraints. It was found that for all water availability scenarios, no water distribution strategy satisfied the domestic demand, leading to propositions for investment in system upgrades along with improved use efficiency. Güner (2008) applied evolutionary game theory to explain how issues of water and territory in the Euphrates and Tigris Basin dominated relations between Turkey and Syria. Eleftheriadou & Mylopoulos (2008) implemented interconnected game theoretical concepts in the case study of Greek–Bulgarian negotiations on the Nestos transboundary river to achieve balanced management of the river water. Lee *et al*. (2011) applied a cooperative two-person non-zero-sum game for the management of multi-purpose dams and allocation of the benefits and costs associated with them between North Korea and China. Soubeyran & Tomini (2012) assessed the risk of a conflict between riparian states sharing international water. Using a Nash bargaining framework, they showed that the risk for conflict increases as the level of scarcity and asymmetry in water productivity increase.

The game developed in the present study includes two players. The first player is the Municipal Enterprise for Water and Sewage of Chania (MEWS) with the ability to change the tariff policy, while the second player is Chania's residents with the ability to change their consumption behavior. Such changes may aim toward water saving to minimize the amount of money paid for water consumption and maintain the water resources. The chosen game follows a non-mixed strategy, which means that every player has only one strategic choice to make at a time, while each strategic choice has equal probability. The main purpose of this survey is to produce payoff matrices that depict the cost of each player's strategies and identify the equilibrium point that corresponds to the optimal decision for both players.

This work presents a methodological framework that accounts for the development and assessment of domestic water pricing policies involving distributors and consumers. It focuses on the development of a fair water consumption tariff policy based on game theory principles, considering the opinion of the consumers and ensuring legitimate revenue for the management and distribution enterprise while encouraging citizens to minimize water consumption. The case study applied here was chosen to demonstrate the applicability of the proposed theoretical application. In addition, significant information on financial and consumption data was provided by MEWS to develop the proposed scenarios. Moreover, the citizens' opinions on this issue were easily expressed and collected through a questionnaire, as the scope of this work was a direct concern to them.

Methods

Case study

The island of Crete, the fifth largest island in the Mediterranean Sea, is located in the southern part of the Aegean Sea. Moreover, since Crete straddles two climatic zones, the Mediterranean and the North African, it is characterized as a semi-arid region. The Municipality of Chania, located in the west-north region of Crete, encompasses an area of 356 km^2 and exhibits mostly flat topography. Due to the existence of steeper slopes in the south, where the mountain range of Lefka Ori is located, the annual precipitation is relatively high considering the dry sub-humid climate of the region. Specifically, the mean annual precipitation is about 665 mm, from which 65% is lost due to evapotranspiration and 21% as runoff to the sea (Chartzoulakis *et al*., 2001). Rainfall is mostly distributed among the winter months, leading to a dry period of more than six months.

The Municipality of Chania accommodates approximately 108,000 residents. The economic development of the region is primarily based on agricultural and touristic activities, two factors that strongly affect water resource availability. In Crete, agriculture accounts for the usage of more than 80% of the abstracted water, while domestic water accounts for 12% (Chartzoulakis *et al*., 2001). Hence, the sustainable development of the region is significantly based on the quantity and quality of the regional water resources.

According to the Greek Joint Ministerial Decision (1991), the lower water consumption limit for domestic use is considered to be 100 $L\ d^{-1}$ per capita in Greece, while the upper limit is 200 $L\ d^{-1}$

per capita, resulting in a mean consumption of 150 L d^{-1} per capita. As a result, the Municipality of Chania is expected to exploit approximately 6 Mm^3 annually for domestic usage, without taking into account possible leakages throughout the supply system.

MEWS is one of the first established enterprises in Greece. Moreover, MEWS is a private legal entity with a public welfare, non-profit character that aims at the design, construction, maintenance, exploitation, management, and operation of Chania's water and wastewater network.

MEWS abstracts spring water that is transported, through two pipelines, to the central tank located at Chania for distribution to the domestic water users. The annual pumping amount is estimated at 16 Mm^3. Nevertheless, this amount is insufficient during the summer periods. Thus, MEWS additionally purchases approximately 2 Mm^3 of groundwater from wells, on an annual basis, to cover this deficit.

As in most MEWSs in Greece, in the City of Chania, the domestic water tariff policy is based primarily on fixed charges, for the management of the water supply network, rather than on volumetric consumption coefficients. As a result, the net value of water is highly underestimated, leading to unfair terms for water bills. In particular, fixed charges are as high as 18.90€ and cover pumping and operation costs. Volumetric water consumption is divided into six blocks for a three-month billing period. Each block is assigned to two volumetric consumption coefficients, a_i and b_i, that account for water supply and wastewater production, respectively (Table 1). Coefficient b_i is calculated as 75% of coefficient a_i, as established by a decision of the Municipal Council in June 2014.

Research methodology

The main idea of this study revolves around the optimal domestic water tariff policy in the Municipality of Chania, Crete in terms of environmental, social, and economic perspectives. Since the MEWS and consumers have conflicting interests, the problem is simulated using a zero-sum game. Three scenarios were developed by gradually reducing the fixed charges and at the same time distributing the amount of money for the consumed water among the consumption blocks in a fair way. Since the MEWS operates as a non-profit organization, it is assumed that the enterprise does not aim to increase its profits. However, to maintain or improve its current quality of services, it is necessary to sustain its current profits.

Table 1. MEWS's volumetric consumption blocks and the assigned volumetric consumption coefficients $\boldsymbol{a_i}$ and $\boldsymbol{b_i}$ for the volumetric water consumption and wastewater production.

Volumetric block, i (m^3)		Volumetric Consumption Coefficient, a_i (€ m^{-3})	Wastewater Production Coefficient, b_i (€ m^{-3})	$a'_i = a_i + b_i$ (€ m^{-3})
1	0–15	0.39	0.30	0.69
2	16–30	0.50	0.37	0.87
3	31–60	0.71	0.53	1.24
4	61–120	1.21	0.90	2.11
5	121–180	1.62	1.21	2.83
6	181 <	1.74	1.30	3.04

The coefficient $\boldsymbol{a'_i}$ represents the sum of the $\boldsymbol{a_i}$ and $\boldsymbol{b_i}$ coefficients.

Assuming that water consumption is Q (m^3 trimester^{-1}) and that it falls into the n volumetric block, the volumetric charge (VC) for water is

$$VC = \sum_{i=1}^{n} Q_i a_i + \sum_{i=1}^{n} Q_i b_i = \sum_{i=1}^{n} Q_i (a_i + b_i), \tag{1}$$

By adding the fixed charges for water supply, which is 12€, and wastewater production, which is 6.90€, the total fixed charge (FC) is calculated: $FC = 18.90 \approx 19$€. Thus, the total value (TV) of water is

$$TV = FC + VC, \tag{2}$$

Assuming that $(a_i + b_i) = a'_i$, the total equation becomes

$$TV = FC + \sum_{i=1}^{n} Q_i a'_i, \tag{3}$$

It should be highlighted that Equation (3) does not include variable charges and fees. In addition, the highest volumetric block (Block 6) is excluded from the study, since this work focuses on the domestic water tariff policy. The remaining blocks are represented by their upper limit values (Table 2), symbolized as RV_i, in the following calculations.

MEWS measures water consumption per hydrometer, a practice also followed in this work. Moreover, based on MEWS considerations in 2015, it is assumed that one hydrometer refers to a mean number of two residents and that the municipality counts approximately 62,500 ($NH - No.\ of\ Hydrometers$) active hydrometers in total.

Questionnaire

As mentioned, the applied policy in the Municipality of Chania does not motivate consumers toward water saving, while at the same time, it is unfair toward those who under-consume. This inference was confirmed by an anonymous online poll of 102 people conducted as part of this work in 2015, where public opinion was recorded on eight questions (Q1–8) relevant to the subject (Figure 1). The questionnaire was uploaded to the official website of the Municipality of Chania and the Technical University of Crete as well as to several local social media websites.

According to the poll, 66.7% of the respondents considered themselves aware of MEWS's applied tariff policy (Q5) (i.e., the fixed charges and the distribution of volumetric charges into the consumption

Table 2. Consumption blocks (i) categorized according to volumetric consumption and representative value (RV_i) of each block.

New volumetric block, i (m^3)		Representative value, RV_i (m^3 hydrometer^{-1} trimester^{-1})
1	0–15	15
2	16–30	30
3	31–60	60
4	61–120	90
5	121–180	180

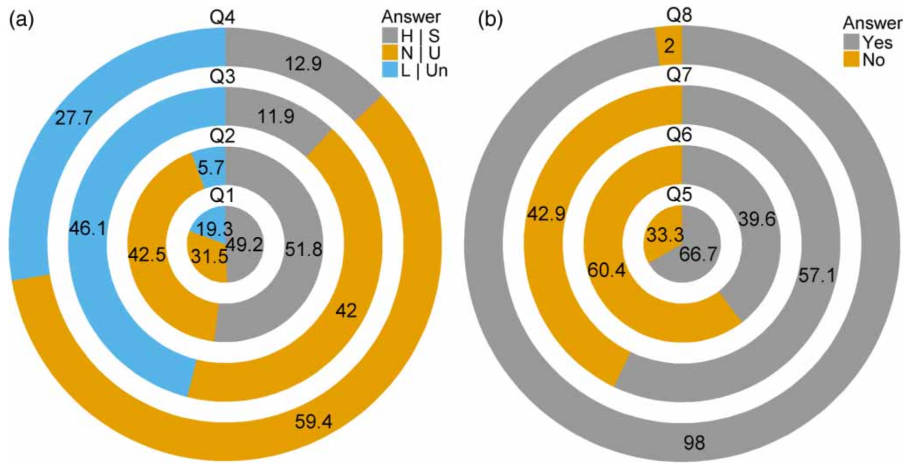

Fig. 1. Results, expressed as percentages, of online poll conducted from October to December 2014. 76 residents were asked the following eight questions: Q1. How satisfied are you with water services? (Satisfied| Unsatisfied| Unaware), Q2. You consider the amount you pay to be (High| Low| Normal), Q3. How fair do you consider the tariff policy? (H| L| N), Q4. Based on water consumption, you consider yourself to be (H| L| N), Q5. Are you aware of the applied tariff policy? (Yes| No), Q6. Does the tariff policy affect your consumption habits? (Y| N), Q7. Would a potential increase in the cost of water change your consumption habits? (Y| N) and Q8. Should the tariff policy be proportional to the water volume consumed? (Y| N).

blocks). However, more than 40% were unsatisfied with the current tariff policy (Q3), while at the same time, more than 50% of the respondents seemed to be quite satisfied with MEWS's current services (Q1). Additionally, more than 50% considered the amount of money they paid to be high enough (Q2), and 57.1% of them agreed that a potential increase in the cost of water would lower their consumption (Q7). However, 60.4% of the responders claimed that the current tariff policy did not affect the amount of water they consumed (Q6). Finally, 98% of the respondents agreed that the tariff policy should be proportional to the water volume consumed (Q8). Poll results suggested that the investigation of the tariff policy in the Municipality of Chania, Crete is an important issue in terms of protecting water resources as well as encouraging users to reduce water consumption.

Scenarios

The game developed in the present study involves two players: MEWS with the ability to change the tariff policy and Chania's residents whose strategies emerge from their consumption behavior. Based on the results of Q8 (Figure 1), three scenarios of gradually reduced fixed charges were developed to describe the available strategies of MEWS. The first scenario, Scenario A, sets fixed charges equal to zero (FC_1= 0.00€), while the second, Scenario B, and the third, Scenario C, consider them as $(1/3)\,FC$ (FC_2= 6.30€) and $(2/3)\,FC$ (FC_3= 12.60€), respectively. New values of a_i', were established for each scenario symbolized as $c_{i,j}$ (where the index i represents the consumption blocks and j represents the discussed tariff policy) to allocate the burden from the reduced fixed charges into the volumetric consumption (Table 3). Lower consumption blocks were charged with lower a_i' values to favor those users that under-consume (or do not over-consume/belong to the first or second consumption block).

Table 3. Coefficient a_i' is calculated as $(a_i + b_i)$ for each new volumetric block i (shown in Table 2) under the currently applied policy, while coefficient $c_{i,j}$ is established for the three scenarios in response to FC.

Block, i (m^3)		Coefficient a_i' Current	Coefficient $c_{i,j}$ (€ m^{-3}) Scenario A	Scenario B	Scenario C
1	0–15	0.69	0.70	0.50	0.40
2	16–30	0.87	0.90	0.85	0.65
3	31–60	1.24	2.35	2.05	1.95
4	61–120	2.11	4.00	4.00	3.65
5	121–180	2.83	5.00	5.00	4.60

The proposed alternative tariff scenarios are expected to trigger a change in consumers' habits. An increase in the water bill (Q7 in Figure 1) is thought to promote water saving and raise consumers' awareness regarding environmental issues (Keramitsoglou & Tsagarakis, 2011; Lee *et al*., 2016). Ideally, the most appropriate method to investigate whether the proposed water tariff scenarios will have an impact on consumers' behavior is through a small-scale implementation, yet such methods tend to be time-consuming and expensive and are inhibited by institutional limitations. Thus, in order to capture the consumers' response to the proposed tariff scenarios, three scenarios describing a low, medium, and high consumer response were created (Table 4). It should be underlined that even if MEWS maintains its current tariff policy, there is a possibility that users may reduce water consumption due to raised awareness.

To determine the profit of the enterprise, it was necessary to specify the percentage of the hydrometers for each block that consumes the equivalent volumetric amount of water. The distribution of hydrometers to the consumption blocks for the current water tariff policy was provided by MEWS for each of the four billing periods of 2015. These data provide the percentage of the hydrometers that fall into or exceed a specific volumetric block. For instance, if a hydrometer consumes 55 m^3, it will be incorporated into the first three blocks (0–15, 16–30, and 31–60 m^3) but not the higher classes (61–120 and 121–180 m^3). To avoid seasonal variations in distribution values, the average value of these four consumption periods was calculated and used for further analysis (Table 4).

The average consumption is considered to be 150 L d^{-1} per resident, yielding a mean consumption of 27 m^3 per trimester per hydrometer. Therefore, it was inferred that half of the hydrometers currently fall into the second consumption block, an assumption that is in line with the data obtained from MEWS. The distribution of hydrometers for the three developed scenarios in the five volumetric classes followed

Table 4. Distribution of consumers among volumetric classes (i) for the current situation (2015) and the three developed scenarios (Low, Medium and High) created to simulate residents' response.

Block, i (m^3)		Current (%)	Low (%)	Medium (%)	High (%)
1	0–15	99.96	99.96	99.96	99.96
2	16–30	58.28	58.28	58.00	57.50
3	31–60	34.81	32.00	30.00	28.00
4	61–120	9.03	9.00	8.50	7.50
5	121–180	2.34	2.00	1.50	1.00

Data for the distribution under the current tariff policy were provided by MEWS.

a gradual reduction in terms of the consumers' response to the new tariff policy proposed in each scenario. Only the distribution of hydrometers in the first class, which assure the water volume used by every household to cover basic needs, remained stable.

The total profit of MEWS is estimated from the sum of the total value of volumetric consumption and the fixed charge, as shown in Equation (3). The volumetric water consumption of its block Q_i (m^3 $trimester^{-1}$) can be calculated as the product of the representative value for its volumetric block RV_i (m^3 $hydrometer^{-1}$ $trimester^{-1}$) (Table 2), the number of hydrometers NH, which is equal to 62,500, and the coefficient PD_i, which describes the distribution of the population among the volumetric blocks (Table 4). Thus, the total volumetric water consumption Q_k (m^3 $trimester^{-1}$) for the consumption scenario k describing consumers' habits can be calculated as

$$Q_k = \sum_{i=1}^{n} (RV_i \cdot PD_{i,k} \cdot NH), \tag{4}$$

while the percentage of water saved (WS) due to the change in consumption habits can be determined by

$$WS\ (\%) = \frac{Q_{current} - Q_k}{Q_{current}}, \tag{5}$$

To this end, MEWS's total profit based on its strategy and consumers' habits can be calculated in € from Equation (6):

$$TP_{jk} = NH \cdot FC + \sum_{i=1}^{n} \left[c_{i,j} \cdot (RV_i \cdot PD_{i,k} \cdot NH) \right], \tag{6}$$

where $TP_{j,k}$ is MEWS's total profit (€) and $c_{i,j}$ is the new consumption coefficient for block i and policy j, as shown in Table 3. Furthermore, the differential percentage (DP) between the current total profit ($TP_{current,current}$) and the developed scenarios may be determined as follows:

$$DP_{j,k}\ (\%) = \frac{TP_{current,current} - TP_{j,k}}{TP_{current,current}}, \tag{7}$$

Results and discussion

Water saving

Based on the three above-mentioned scenarios concerning the consumer behavior of Chania's residents, the water saving (WS) (Equation (5)) is expected to increase substantially, as illustrated in Figure 2. The low response scenario provokes a 2.2% decrease in water consumption, while the medium and high response scenarios provoke a 4.6% and 7.8% decrease, respectively. The differences among the three scenarios are significant, yet they were developed this way in order to capture the uncertainty concerning the residents' response to the new tariff policy applied.

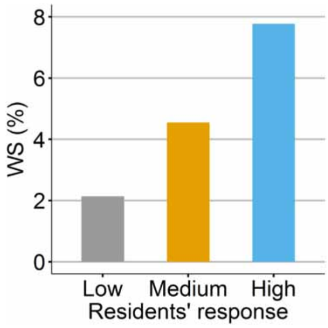

Fig. 2. Water saving under the Low, Medium and High scenario concerning the behavioral response of the residents of Chania.

Pay-off table

The differential percentage (*DP*), calculated as illustrated in Equation (7), is shown in Table 5 under all the examined scenarios. The values in Table 5 correspond to the variable percentages of the gains and losses between the current and the three examined public responses for each tariff policy scenario. Positive values stand for consumers' losses and MEWS's profits. MEWS's profit may also be considered residents' loss. It should also be mentioned that the medium response for all three tariff policy scenarios manages to maintain MEWS's current profit without putting the company's operation in jeopardy, while the medium response scenario for the current tariff policy reduces MEWS's profit by 5.93%.

Since the game is described as a zero-sum game, every solution achieved is considered an equilibrium point. Subsequently, even the current situation portrayed in the pay-off matrix is an equilibrium point. However, this point is not considered the optimal solution when compared to the new proposed scenarios. When MEWS decides to apply one of the proposed scenarios A, B, or C or the rise of residents' awareness moves their consumption habits toward a water-saving strategy, as suggested in the low, medium, and high response scenarios, the game is expected to reach a new equilibrium point that corresponds to the optimal decision for both players. As observed, the medium response scenario seems to present the lowest fluctuations in the value of the total profit that ranges between −0.07% and −5.93%. The medium response scenario also acts in favor of consumers, along with the high response scenario, regardless of the strategy followed by MEWS. Otherwise, if consumers fail to adapt their consumption habits to the new suggested tariff policies, their loss may rise from 9.71% to 10.82%. Similarly, a high response to each proposed charging strategy may boost consumers' profits from 7.48% to 10.32%.

Table 5. DP for the current and the three examined public responses (Low, Medium and High response) under the currently applied tariff policy and the three developed scenarios (Scenario A, Scenario B and Scenario C).

DP (%)		MEWS's strategies			
		Current Policy	Scenario A	Scenario B	Scenario C
Consumers' responses	Current	0.00	10.82	10.40	9.71
	Low	−2.51	6.07	6.04	5.61
	Medium	−5.93	−0.09	−0.07	−0.11
	High	−10.32	−8.68	−8.13	−7.48

The purpose of this matrix is to determine the optimal equilibrium point. This game has at least one equilibrium point, for which both players choose the most advantageous strategies, being aware of each other's choices. One player's strategy is the best response to the strategy of the other player. In the case of Player 1 (MEWS), the best strategy includes the implementation of a scenario that will have the lowest effect on its current profits (i.e., the scenario that will minimize MEWS's loss and at the same time ensure the highest possible water saving). On the other hand, the best strategy for Player 2 (water users) is a response that will maximize their profits (i.e., a response that will reduce the volumetric consumption of water and therefore lower the quarterly water account). The game hence exhibits the optimal equilibrium at $\pm 0.07\%$, which ensures that Player 2 (water users) will benefit with a medium response to Scenario B and that Player 1 (MEWS) will have the lowest deviation from its current profits.

This work presented a framework of domestic water tariff policies development based on a zero-sum game between consumers and the domestic water distribution enterprise toward water saving, social awareness, and economic viability. The qualified water policy scenario favors the public's demand for a consumption-based tariff policy focused on water-saving awareness while minimally affecting the profits of the water distribution enterprise. In a similar work (Amit & Ramachandran, 2010), the two parties agreed to a fair and economically efficient domestic water supply contract, but in case of financial deviation by the agent, the loss was to be covered by the consumers. In addition, uniform consumption charges under price elasticity are not uniform across users, as high-income consumers may adapt but low-income consumers close to subsistence level may not (Olivier, 2010). Furthermore, the basic domestic water-tariff policies applied around the world (Pinto & Marques, 2015) have as their primary target the profit of the distribution enterprise, encouraging water savings through value/m^3 in scaled or plane forms without, in most of the cases, considering social awareness. In contrast to those practices, the methodology applied here activates the citizens' awareness of water saving through a fairer tariff policy to which they have contributed. The qualified scenario is in favor of consumers saving money and considers a scaled charge of volumetric consumption in excess of the reduced fixed charges to protect low-income consumers. This work presented that the active participation of consumers and domestic water distribution enterprises in the design of water tariff policy scenarios can lead to the sustainable allocation of the water supply and use costs. In addition, it aimed to support decision making on water tariff policies by considering the citizens' contribution in terms of a public opinion poll. This hybrid water-tariff policy of reduced fixed charges and variable volumetric consumption cost that favors water saving, considering at the same time the financial sustainability of the domestic water management and distribution enterprise, could be a pilot application for improved water tariff policies. Furthermore, the application of game theory in the assessment of the developed scenarios shows that an optimum equilibrium between the consumers and the water enterprise can be reached that will leave everyone satisfied regarding their priorities, leading also to significant water savings. Thus, it could be a base for decision making on water tariff policies.

Conclusions

During the next decades, water resource exploitation is expected to worsen, mainly due to population growth. Domestic water management has not received enough attention, since it only accounts for a small fraction of total water needs. On top of that, the scientific community predominantly focuses on technical improvements, while only a limited number of studies adopt socioeconomic approaches. Nevertheless, policy-making strategies, such as those involving domestic water tariff policies, can facilitate a two-fold objective by protecting natural resources while raising public awareness.

The purpose of this paper was to propose alternative tariff policies for domestic water by adopting basic principles of game theory, a useful tool for describing conflicts involving a common resource. The Municipality of Chania, Greece was selected as the case study area where the water tariff policy is mainly based on fixed charges, while the public argues that a tariff policy based on water volumetric consumption would be fairer. To this end, a two-player, zero-sum game was set and developed according to the basic principles of game theory. The results of this game indicated that a new equilibrium point can be achieved ensuring minimum fluctuations in MEWS's profits and at the same time saving fair amounts of the asset. Specifically, the optimal equilibrium point was achieved at $\pm 0.07\%$, representing consumers' medium response to MEWS's Scenario B (one-third of the initial total fixed charge). The selected strategy manages to curtail water consumption by as much as 4.6%. The scenarios assessed in this work were based on an online poll that expressed the citizens' opinions specifically on the matter of the tariff policy and on water savings awareness without considering the personal characteristics of the contributors. However, some limitations of this work must be considered in future applications, such as the collection of a greater number of questionnaires to consider the different financial and educational backgrounds of the contributors as well as an age scale in the number of collected questionnaires. Although the last two limitations were theoretically addressed by the authors, explicit information may influence further analysis.

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Authors' contribution

All the authors as a team set up the research idea and methodology. The first author supervised this work, interpreted and discussed the results as well as managed and edited the text structure and insights. The other authors as a team organized the poll procedure, ran the methodology, produced the results and contributed to the manuscript preparation.

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