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Cooperative water management and ecosystem protection under scarcity and drought in arid and semiarid regions

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ABSTRACT

Climate change impacts and the growing concern on environmental water demand are further increasing competition for scarce water resources in many arid and semiarid regions worldwide. Under these circumstances, new water allocation mechanisms based on the involvement of stakeholders are needed, for an efficient and fair allocation of water and income among users. This paper develops a cooperative game theory framework in order to analyze water management policies that could address scarcity and drought in a typical arid and semiarid basin in Southeastern Spain. The results provide clear evidence that achieving cooperation reduces drought damage costs. However, cooperation may have to be regulated by public agencies, such as a basin authority, when scarcity is very high, in order to protect ecosystems and maintain economic benefits. The cooperative game theory solutions and stability indexes examined in this paper demonstrate the importance of incorporating the strategic behavior of water stakeholders in the design of acceptable and stable basin-wide drought mitigation policies.

1. Introduction

Global water resources are under increasing pressures that create growing water scarcity and quality problems, giving rise to complex social conflicts and environmental degradation. Water extractions across the world have increased more than six fold in the last century, much above the rate of population growth [1]. It is estimated that about 35% of the world population suffers from severe water stress and about 65% of global river flows and aquatic ecosystems are under moderate to high threats of degradation [2,3].

Water scarcity has become widespread in most arid and semiarid regions, including river basins such as the Yellow, Jordan, Murray-Darling, Colorado, and Rio Grande [1,4]. Projected future climate change impacts would further exacerbate the current situation of water scarcity in arid and semiarid regions. These regions would likely suffer a decrease in water resources availability and experience longer, more severe, and frequent droughts [5].

Emerging social demands for environmental protection in the form of secured minimum flows for water-dependent ecosystems further increase competition for already scarce water in arid and semiarid regions, especially during dry years. Water-dependent ecosystems, such as wetlands, provide a diverse range of goods and services to society, including habitat for valuable species, flood control, groundwater replenishment, water quality improvement, waste disposal, and recreational opportunities [6]. However, water-dependent ecosystem services are

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external to markets, and their social values are overlooked in water allocation decisions. For instance, an estimated 50% of world wetlands have disappeared over the last century [7].

Several policy responses have been suggested to cope with water scarcity and to mitigate the negative impacts of droughts for the different water use sectors. These policies include reducing water allocations, water transfers, conjunctive use of ground and surface waters, groundwater banking, recycling and reuse of wastewater, seawater desalination, improving water use efficiency, adopting water conserving-technologies, changing crop mix, setting minimum environmental flows, and implementing economic instruments such as water pricing and water trade including water purchases for environmental purposes.

These policy alternatives have been previously analyzed in several studies such as Booker et al. [8]; Howitt et al. [9]; Kirby et al. [10]; and Zilberman et al. [11]. However, the existing literature, while assessing solutions to drought situations using engineering, economic and institutional approaches, usually overlooks one important aspect, which is the strategic behavior of individual stakeholders. The analysis of the strategic behavior of stakeholders is essential for testing the acceptability and stability of policy interventions aimed at basin-wide drought mitigation.

This gap is addressed in this paper by developing a cooperative game theory (CGT) framework in order to analyze water management policies aimed to deal with scarcity and drought at a basin scale. The paper contributes to the literature on water policy through the inclusion of the strategic behavior of various stakeholders and the ecosystem benefits in the river water management problem. Several CGT solution concepts and stability indexes are used to find efficient and fair allocations of water and income among river water users under various climate scenarios. In addition, the analysis considers the likelihood of succeeding in ecosystem protection.

The CGT deals with games in which stakeholders (players) choose to cooperate by forming coalitions and sharing fairly the benefits from those coalitional arrangements. In particular, CGT favors agreements that include all possible players (grand coalition) and it provides several benefit sharing mechanisms (solution concepts) based on different notions of fairness. The purpose is to find the incentives for cooperation among stakeholders in order to achieve economic efficient outcomes for the coalitions. The advantage of using CGT compared to conventional optimization models is its ability to address both efficiency and equity principles, which would promote acceptable and stable cooperative outcomes [12]. CGT models were developed and have been applied to various aspects of water management in the literature, such as decisions on cost and benefit allocation in multipurpose water projects, efficient sharing of river systems, joint management of groundwater aquifers, optimal operation of hydropower facilities, and resolution of transboundary water conflicts [13–15].

The CGT framework is applied to the Jucar River Basin (JRB) of Spain, which is a good case for studying the strategic behavior of stakeholders and policies to confront water scarcity and drought impacts from the impending climate change. The JRB region is semiarid and the river is under severe stress with acute water scarcity problems and escalating degradation of ecosystems. Another interesting aspect of the JRB is that there have been already successful policies leading to stakeholders' cooperation. In particular, the curtailment of water extractions in the Eastern La Mancha aquifer that were threatening the activities of downstream stakeholders [16].

2. Cooperative game theory framework

This section presents the CGT framework used to analyze water management policies addressing scarcity and drought at basin scale. Assume that a basin includes $n > 1$ users (players in the game). The users consider a cooperative management of the basin by agreeing to share water resources. Initially, the users have predetermined administrative water allocations depending on the climate condition. Under the cooperative water sharing agreement, the agency responsible for water allocation reallocates water among uses so that the whole basin benefits are maximized. When additional benefits are obtained through this cooperative agreement compared to non-cooperation (status quo), the water agency needs to distribute these benefits among the cooperating users in a fair way that would sustain cooperation.

Let N be the set of all players in the game, S is the set of all feasible coalitions, and s ($s \in S$) is one feasible coalition. The singleton coalitions are $\{l\}$, $l = 1,2,\ldots, n$, and the grand coalition is $\{N\}$. Assume that the objective of the water agency is to maximize the benefits, f^s, of any feasible coalition in the basin, s, by efficiently allocating water among the players in that coalition. Let $\nu(s)$ be the characteristic function of coalition s, which is the best value that such coalition can obtain. The cooperative water sharing agreement takes the following form:

$$\nu(s) = Max\, f^s = \sum_{l \in s} B_l \tag{1}$$

subject to

$$\sum_{l \in s} WU_l \le WA_s \tag{2}$$

where B_l is the private net benefits from water use of player l in coalition s. The water constraint (2) states that the sum over players, l, in coalition, s, of water use by each player, WU_l, must be less than or equal to water available for that coalition, WA_s.

When additional benefits are obtained through this cooperative agreement compared to non-cooperation, the water agency overseeing the agreement needs to allocate these benefits among the cooperating players in a fair way in order to secure the acceptability and stability of the agreement. These allocations could be determined using the CGT solution concepts. A necessary condition for cooperation in the basin is that the benefits obtained by each cooperating player under full cooperation (grand coalition) are greater than what each player can obtain under non-cooperation (singleton coalition), or by participating in partial cooperative arrangements (partial coalitions).

Let Ω_l^a be the allocated cooperative benefit (payoff) to player l using the CGT solution concept, a. A feasible cooperative allocation should satisfy the following three requirements:

$$\Omega_l^a \geq \nu(\{l\}) \quad \forall\, l \in N \tag{3}$$

$$\sum_{l \in s} \Omega_l^a \geq \nu(s) \quad \forall\, s \in S \tag{4}$$

$$\sum_{l \in N} \Omega_l^a = \nu(N) \tag{5}$$

Eq. (3) fulfills the condition for individual rationality, which means that the allocated benefits from full cooperation to player l, Ω_l^a, must be greater than or equal to its benefits from non-cooperation, $\nu(\{l\})$. Eq. (4) fulfills the group rationality condition, which means that the sum of full cooperative benefit allocations to any group of players, $\sum_{l \in s} \Omega_l^a$, must be greater than or equal to the total obtainable benefits under any coalition s that includes the same players, $\nu(s)$. Eq. (5) fulfills the efficiency condition, which means that the total obtainable benefits under the grand coalition, $\nu(N)$, must be allocated to the members of that coalition, $\sum_{l \in N} \Omega_l^a$.

An allocation that satisfies these three requirements is in the Core of the cooperative game [17]. The Core is a set of game allocation gains that is not dominated by any other allocation set. The Core provides information about the range of acceptable solutions for each player and allows for ranking the players' preferences over the possible cooperative solutions. Satisfying the Core conditions for a cooperative solution is a necessary condition for its acceptability by the players. Therefore, solutions not included in the Core are not acceptable and not stable [18].

Three CGT solution concepts based on different notions of fairness are used in this paper to allocate the gains from cooperation among the players: the Shapley value, the Nash–Harsanyi, and the Nucleolus.

The Shapley value allocates Ω_l^{Sh} to each player based on the weighted average of their contributions to all possible coalitions. The Shapley value is based on the intuition that the allocation that each player receives should be proportional to his contribution. Players who add nothing, should receive nothing and players who are indispensable should be allocated a lot [19]. The Shapley solution takes the following form:

$$\Omega_l^{Sh} = \sum_{\substack{s \in S \\ l \in s}} \frac{(n - |s|)!(|s| - 1)!}{n!} \cdot (\nu(s) - \nu(s - \{l\}))\ \forall\, l \in N \tag{6}$$

where n is the total number of players in the game, $|s|$ is the number of players participating in coalition s, and $\nu(s - \{l\})$ is the value of coalition s without member l.

The Nash–Harsanyi solution [20] to an n-person bargaining game is a modification to the two-player Nash solution [21]. This solution provides an allocation to each player, Ω_l^{NH}, by maximizing the product of the incremental gain of the players from cooperation. The Nash–Harsanyi solution takes the following form:

$$Max \prod_{l \in N} (\Omega_l^{NH} - \nu(\{l\})) \tag{7}$$

subject to the Core conditions (Eqs. (3)–(5)). The Nash–Harsanyi solution is unique and it is in the Core (if it is not empty).

The Core of a cooperative game in the characteristic function form may be empty because certain partial coalitions provide greater payoff than the grand coalition. Conversely, conditions may arise where the Core does exist but is too large and leaves the allocation problem open for further bargaining. The Nucleolus solves this problem by minimizing the worst inequity or dissatisfaction of the most dissatisfied coalition [22]. The Nucleolus of the benefit allocation game can be determined by finding ε through the following optimization model:

$$Max\ \varepsilon \tag{8}$$

subject to

$$\varepsilon \leq \sum_{l \in s} \Omega_l^{Nu} - \nu(s) \quad \forall\, s \in S \tag{9}$$

$$\sum_{l \in N} \Omega_l^{Nu} = \nu(N) \tag{10}$$

$$\varepsilon \lesseqqgtr 0 \tag{11}$$

where ε is the maximum tax imposed on or subsidy provided to all coalitions to keep them in the Core. The Nucleolus allocation, Ω_l^{Nu}, is a single solution that is always in the Core, if the Core is not empty.

The fulfillment of the Core requirements for a CGT allocation solution is a necessary condition for its acceptability by the players. However, being in the Core does not guarantee the stability for a solution, as some players may find it relatively unfair compared to other solutions. The consequence is that some players might threaten to leave the grand coalition and form partial coalitions because of their critical position in the grand coalition [23]. The stability of any solution is important given the existence of considerable fixed investments and transaction costs, so that a more stable solution might be preferred even if it is harder to implement.

Some methods are suggested in the literature to evaluate the stability of the CGT allocation solutions [23]. For instance, Loehman et al. [24] used an ex-post approach to measure power in a cooperative game. This approach is similar to the one suggested by Shapley and Shubik [25] for measuring power in voting games. The Loehman power index (θ_l^a) compares the gains to a player with the gains to the coalition. The power index is the following:

$$\theta_l^a = \frac{\Omega_l^a - v(\{l\})}{\sum_{l \in N} \left(\Omega_l^a - v(\{l\})\right)}, \quad \sum_{l \in N} \theta_l^a = 1, \quad a = Sh,\ NH,\ Nu \tag{12}$$

where Ω_l^a is the allocation solution for player l using the CGT solution concept a. The power index of each player is used as an indicator of the stability of the allocation solution. The higher the power index of a player, the higher that player's interest in cooperating and staying in the grand coalition. If the power is distributed more or less equally among the players, then the coalition is more likely to be stable. The coefficient of variation of the power indexes of the different players for an allocation solution is defined as the stability index of the grand coalition $\overline{\theta_a}$. The greater the value of $\overline{\theta_a}$ the larger the instability of the allocation solution.

The theoretical CGT framework proposed in this section is applied to the water management problem in the JRB. The next section describes the empirical river basin model of the JRB that is used to calculate the value of the characteristic function of various coalitional arrangements.

3. Empirical river basin model

The empirical river basin model includes the main users in the JRB: irrigation activities, urban uses, and aquatic ecosystems needs. A specific model for optimizing each and all water use sectors has been built, and these models are linked, using a reduced form hydrological model developed and calibrated to the JRB conditions by Kahil et al. [26].

3.1. Study area

The JRB is located in the regions of Valencia and Castilla La Mancha in Southeastern Spain and it extends over 22,400 km^2 (Fig 1). Renewable water resources in the JRB are nearly 1700 Mm^3. Water extractions are 1680 Mm^3, very close to renewable resources, making the JRB an almost closed water system [27].

Extractions for irrigated agriculture are about 1400 Mm^3 per year, which represent 84% of total water extractions, to irrigate 190,000 ha. The major irrigation districts are: the Eastern La Mancha aquifer district (EM) in the upper Jucar, the traditional districts of Acequia Real del Jucar (ARJ), Escalona y Carcagente (ESC) and Ribera Baja (RB) in the lower Jucar, and the the Canal Jucar-Turia district (CJT) situated in the adjacent Turia River Basin. Urban and industrial extractions are about 270 Mm^3, serving more than one million inhabitants located mostly in the cities of Valencia, Sagunto and Albacete [27].

Expansions of water extractions in the basin and the severe drought spells in recent decades have triggered considerable negative environmental and economic impacts. Environmental flows are dwindling in many parts of the basin, resulting in serious damages to water-dependent ecosystems. The environmental flow in the final tract of the Jucar River is below 1 m^3/s, which is very low compared with the other two major rivers in the region, the Ebro and Segura Rivers. There have been also negative impacts on downstream water users, where water availability has been reduced substantially in the last forty years. Consequently, the dwindling irrigation return flows

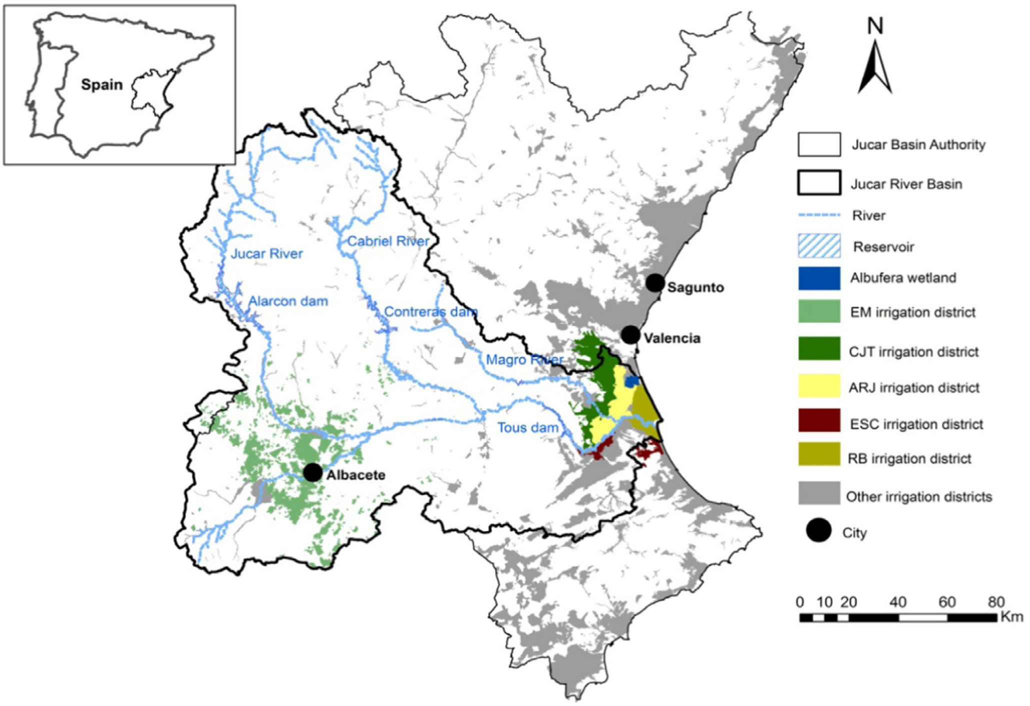

Fig. 1. Map of the Jucar River Basin.

in the lower Jucar have caused serious environmental problems to the Albufera wetland, the main aquatic ecosystem in the JRB, which is mainly fed by these return flows [28].

The Albufera wetland is a freshwater lagoon with an area covering 2430 ha, supporting very rich aquatic ecosystems. Since 1989, the Albufera was included in the list of wetlands of international importance, and was declared a special protected area for birds. The Albufera receives water from the return flows of irrigation in the lower Jucar, mainly from the ARJ and the RB districts. Other flows originate from the Turia River Basin, and from discharge of untreated and treated urban and industrial wastewaters. Currently, the Albufera wetland suffers from reduction of inflows and the degradation of their quality. These problems are driven by the reduced flows originating from the Jucar River, and by deficiencies in the sewage disposal and treatment systems from adjacent municipalities, causing severe damages to the Albufera wetland, such as the loss of biodiversity, the decrease in recreation services, and the decline of fishing activities [29].

3.2. The model

The hydro-economic model of the JRB integrates hydrologic, economic, environmental, and institutional variables within a single framework. The model accounts for decision processes made by irrigators in the five major districts (EM, CJT, ARJ, ESC, and RB) and by urban users in the three major cities (Valencia, Albacete, and Sagunto) in the basin. In addition, the model includes environmental benefits provided by the Albufera wetland to society. Several small demand units in the basin are not included in the model. The model runs on an annual basis, and its main focus is on the allocation and utilization of surface water. Groundwater use and management are not taken into account in this paper.

In order to link the different components of the river basin model and to simulate the spatial impact of drought in the JRB, a reduced form of the hydrological model of the basin is used [27]. The reduced form hydrological model is a node-link network that controls the flows of water in each node and estimates the distribution of available surface water among users in each climate condition, calibrating it to observed water allocations in both normal and drought years. This approach to model river basin hydrology has been used in several studies such as Cai et al. [30]; and Ward and Pulido-Velazquez [31].

The reduced form hydrological model is based on the principles of water mass balance and continuity of river flow, which determine the volume of water availability in each river reach that can be used for economic activities taking into account environmental restrictions. The mathematical formulation of the model is as follows:

$$WO_d = WI_d \cdot (1 - \gamma_d) - D_d^{IR} - D_d^{URB} \tag{13}$$

$$WI_{d+1} = WO_d + r_d^{IR} \cdot (D_d^{IR}) + r_d^{URB} \cdot (D_d^{URB}) \tag{14}$$

$$WO_d \geq E_d^{min} \tag{15}$$

The mass balance Eq. (13) determines the volume of water outflow WO_d from a river reach d, which is equal to the net (of evaporation loss γ_d) water inflow $WI_d \cdot (1-\gamma_d)$ to d minus diversion for irrigation D_d^{IR} and for urban and industrial uses D_d^{URB}. The continuity Eq. (14) guarantees the continuity of river flow in the basin, where the volume of water inflow to the next river reach WI_{d+1} is the sum of outflow from the previous river reach WO_d, the return flows from previous irrigation districts $r_d^{IR} \cdot (D_d^{IR})$ and, the return flows from the cities $r_d^{URB} \cdot (D_d^{URB})$. Eq. (15) states that the volume of water outflow WO_d from a river reach d must be greater than or equal to the minimum environmental flow E_d^{min} established for that river reach, which is determined by the basin's regulations.

We incorporate the reduced form hydrological model into a regional economic optimization model. For irrigation activities, a farm-level optimization model has been developed for each irrigation district. Irrigation districts maximize farmers' private benefits, subject to technical and resource constraints. The optimization problem for each irrigation district takes the following form:

$$Max\ B_k^{IR} = \sum_{ij} C'_{ijk} \cdot X_{ijk} \tag{16}$$

subject to

$$\sum_{ij} A_{ijk} \cdot X_{ijk} \leq R_k \tag{17}$$

$$X_{ijk} \geq 0 \tag{18}$$

where B_k^{IR} is farmers' private benefits in irrigation district k. C'_{ijk} is a vector of coefficients of net income per hectare of crop i cultivated under irrigation technology j. A_{ijk} is a matrix of production coefficients and R_k is a vector of constraint levels including land, water and labor in each irrigation district k. X_{ijk} corresponds to the area of crop i cultivated under irrigation technology j in irrigation district k and it is the decision variable in the irrigation district optimization problem.

For urban water uses, an economic surplus model has been developed for each city. The model maximizes the social (consumer and producer) surplus from water use for each city, subject to several physical and institutional constraints. The optimization problem for each urban center takes the following form:

$$Max\ B_u^{URB} = \left(a_{du} \cdot Q_{du} - \frac{1}{2} \cdot b_{du} \cdot Q_{du}^2 - a_{su} \cdot Q_{su} - \frac{1}{2} \cdot b_{su} \cdot Q_{su}^2 \right) \tag{19}$$

subject to

$$Q_{du} - Q_{su} \leq 0 \tag{20}$$

$$Q_{du}\ ;\ Q_{su} \geq 0 \tag{21}$$

where B_u^{URB} is the social surplus of city u from water use. Q_{du} and Q_{su} are the quantity of water demanded and supplied by/to the city u, respectively. a_{du} and b_{du} are the intercept and the slope of the inverse demand function of city u, respectively. a_{su} and b_{su} are the intercept and the slope of the water supply function for city u, respectively. Eq. (20) states that the quantity of water supplied must be greater than or equal to the quantity demanded.

The river basin optimization model accounts also for the environmental benefits provided by the main aquatic ecosystem in the JRB, the Albufera wetland. The model considers only water inflows to the Albufera wetland originating from irrigation return flows of the ARJ and RB irrigation districts. Inflows and benefits of the Albufera wetland are given by the following expressions:

$$E_{Albufera} = \alpha \cdot r_{ARJ}^{IR} \cdot \left(D_{ARJ}^{IR} \right) + \beta \cdot r_{RB}^{IR} \cdot \left(D_{RB}^{IR} \right) \tag{22}$$

$$B_{Albufera} = \begin{cases} \delta_1 & if \ 0 \le E_{Albufera} \le E_1 \\ \delta_2 + \rho_2 \cdot E_{Albufera} & if \ E_1 < E_{Albufera} \le E_2 \\ \delta_3 + \rho_3 \cdot E_{Albufera} & if \ E_2 < E_{Albufera} \le E_3 \end{cases} \tag{23}$$

where Eq. (22) determines the quantity of water flowing to the Albufera wetland, $E_{Albufera}$. Parameters α and β represent the shares of return flows that feed the wetland from the ARJ and RB irrigation districts, respectively. The products $r_{ARJ}^{IR} \cdot (D_{ARJ}^{IR})$ and $r_{RB}^{IR} \cdot (D_{RB}^{IR})$ are return flows from the ARJ and RB irrigation districts, respectively. Eq. (23) represents environmental benefits, $B_{Albufera}$, that the Albufera wetland provides to society. The environmental benefit function is assumed to be a piecewise linear function of the water inflows, $E_{Albufera}$, to the wetland. This function expresses shifts in the ecosystem status when critical thresholds of environmental conditions are reached (water inflows E_1, E_2 and E_3). This functional form is adapted from the study by Scheffer et al. [32], indicating that ecosystems do not always respond smoothly to changes in environmental conditions, but they may switch abruptly to a contrasting alternative state when these conditions approach certain critical levels. This function has been built following the methodology developed by Jorgensen et al. [33] using time series data of various ecosystem health indicators of the wetland, available from the JRB authority reports, and economic valuation estimates of wetland services from the literature [27,34]. Fig A1 in the appendix shows the environmental benefit function of the Albufera wetland.

The river basin optimization model maximizes total basin benefits subject to the hydrological constraints and the constraints of the individual economic sector optimization models. The optimization problem for the whole river basin takes the following form:

$$Max \left(\sum_k B_k^{IR} + \sum_u B_u^{URB} + B_{Albufera} \right) \tag{24}$$

subject to the constraints in Eqs. (13)–(15), (17), (18), and (20)–(22).

The river basin optimization model allows calculating basin benefits under current institutional setting or baseline scenario (the non-cooperative solution) and it is the basis for calculation of benefits accrued to users under various cooperative arrangements for different drought scenarios.

Detailed biophysical and economic data has been collected from several sources including water inflows and diversions, crop area and water requirements, irrigation efficiency, crop costs and revenues, and water costs and prices by sector. Selected hydrologic and economic parameters of the JRB model are shown in Table 1. The river basin model and the CGT application have been run using the GAMS package. Further details on model development and data sources can be found in Kahil et al. [26].

3.3. Scenario simulation

The main water users in the JRB (described in Section 3.1) are classified into four players that have similar characteristics regarding water use and their relation with the Albufera wetland. Players in the JRB game are: irrigation districts linked to the Albufera including the ARJ and RB irrigation districts (IE); irrigation districts not linked to the Albufera including the EM, CJT, and ESC irrigation districts (INE); the cities including Valencia, Sagunto and Albacete (C); and the Albufera wetland (E). This classification will allow us to capture all important strategic relationship between players in various locations of the basin and their opposed interests, and at the same time to keep the computational burden at a reasonable level.

The cooperative water sharing agreement described in Section 2 (Eqs. (1) and (2)) is applied for two different scenarios of water management. The purpose is to find efficient and fair allocations of water and income among the players, and to explore the likelihood for ecosystem protection success. The scenarios are the following:

3.3.1. Scenario 1

This scenario maximizes the private benefits of the basin under all possible coalitional arrangements. The private benefits are the sum of the benefits of players IE, INE and C, disregarding the environmental benefits provided to society by player E (the Albufera wetland). The wetland receives water from return flows generated by player IE, similar to what happens in the current situation. The wetland is a weak player in the game because it does not compete for water.

3.3.2. Scenario 2

This scenario maximizes the social benefits of the basin under all possible coalitional arrangements. The social benefits are the sum of the benefits of all the players in the game, including the environmental benefits provided to society by player E (the Albufera wetland). In this case, the wetland is competing for water with other users, and does not depend passively on remaining return flows.

These two scenarios are simulated under normal flow and under various drought conditions using two sets of coalitional arrangements. Drought is classified into three levels, depending on the severity of the drought event: mild, severe, and very severe, based on historical data about water inflows in the JRB. The two sets of coalitional arrangements are: (a) partial cooperation in which the two scenarios are run with different combination of players;

Table 1
Parameters of the JRB model.

Parameters	Value	Unit
Total irrigated area	157,000	ha
Cereals area	70,650	ha
Vegetables area	21,980	ha
Fruit trees area	64,370	ha
Flood irrigation area	28,260	ha
Sprinkler irrigation area	58,090	ha
Drip irrigation area	70,650	ha
Average irrigation water price	0.05	€/m^3
Average urban water price	0.71	€/m^3
Share of return flows feeding the Albufera		
ARJ (α)	28	%
RB (β)	23	%
Benefit function of the Albufera from water inflows		
Intercept (δ_1)	33	10^6 €
First threshold of inflows to the Albufera (E_1)	51	Mm^3
Intercept (δ_2)	−214	10^6 €
Slope (ρ_2)	4.8	€/m^3
Second threshold of inflows to the Albufera (E_2)	78	Mm^3
Intercept (δ_3)	43	10^6 €
Slope (ρ_3)	1.8	€/m^3
Third threshold of inflows to the Albufera (E_3)	138	Mm^3
Economic value of the Albufera wetland	13,600	€/ha

Table 2
Benefits under the baseline situation for different climate conditions (10^6 €).

Users	Normal flow	Mild drought	Severe drought	Very severe drought
EM	79.8	71.9	66.4	60.7
CJT	44.9	40.6	37.2	35.7
ARJ	34.1	31.0	27.0	22.9
ESC	7.3	6.8	5.7	4.2
RB	24.2	20.7	16.5	12.1
Irrigation sector	**190.3**	**170.9**	**152.8**	**135.6**
Valencia	216.3	214.0	206.6	186.9
Sagunto	26.1	24.1	22.2	16.8
Albacete	40.2	38.9	38.8	38.6
Urban sector	**282.6**	**277.0**	**267.6**	**242.3**
Albufera wetland	**74.7**	**37.2**	**33.0**	**33.0**
Total JRB	**547.7**	**485.1**	**453.4**	**410.9**

and (b) full cooperation, in which the two scenarios are run with all the players.

4. Results and discussion

The baseline situation (non-cooperation) represents the current conditions of water allocations in the JRB. Each player is maximizing its private benefits from its administrative water allocation, and there is no cooperation in the form of water sharing among the players. The results of the baseline situation are presented in Tables 2 and 3.

Benefits in the JRB under the baseline situation for normal flow conditions amount to 548 million € from using 1149 Mm^3. Irrigation activities generate 190 million € from using 1030 Mm^3. The social surplus of the cities is 283 million € and they use 119 Mm^3. Environmental benefits provided by the Albufera wetland are 75 million €. The Albufera wetland receives 60 Mm^3 from the return flows of the ARJ and RB irrigation districts, which support the good ecological status of the wetland.

Table 3
Water use under the baseline situation for different climate conditions (Mm^3).

Users	Normal flow	Mild drought	Severe drought	Very severe drought
EM	399	359	332	304
CJT	155	132	115	107
ARJ	200	180	155	130
ESC	33	30	25	18
RB	243	207	167	123
Irrigation sector	**1030**	**908**	**794**	**682**
Valencia	94	81	67	53
Sagunto	8	7	6	4
Albacete	17	17	17	17
Urban sector	**119**	**105**	**90**	**74**
Albufera wetland	**60**	**52**	**43**	**34**
Total JRB	**1149**	**1013**	**884**	**756**

Note: total water use in the JRB is the sum of water use in the irrigation and urban sectors, and does not include water return flowing to the Albufera wetland.
The quantity of urban water use shown in the table represents only the part of supply from the JRB. During droughts, the urban sector uses additional water from the Turia River to cover the demand of Valencia and Sagunto. The full demand of Valencia (94 Mm^3) and Sagunto (8 Mm^3) is always covered.

Results of the drought scenarios indicate that drought events reduce the benefits of the JRB between 11% and 25%. Water use patterns show a reduction in extractions between 12% and 34%. Irrigation activities reduce water extractions between 12% and 34%. Irrigation benefit losses range between 10 to 30% of benefits in normal year. The reduction in irrigation water extractions has large negative impacts on the Albufera wetland that is mostly fed by irrigation return flows. Water inflows to the Albufera wetland decrease between 13% and 43%, depending on drought severity. As a consequence, drought damages for the Albufera wetland under drought conditions exceed 50% of benefits in normal years.

The current water resources regulation in the JRB guarantees the availability of urban water to human population. During severe drought spells, the urban demand must be first fully covered because of such priority rules. The three simulated drought scenarios show a reduced supply from the Jucar River to the main cities in the JRB. However, the full demand of Valencia and Sagunto is always covered with additional water from the neighboring Turia River Basin. During extreme drought periods, the provision of water to these cities is shared equally between the Jucar and the Turia Rivers. In the city of Albacete, the supply of water during dry periods is amended by pumping groundwater from the Eastern La Mancha aquifer [27]. The simulation results for the urban sector indicate that the provision of surface water from the Jucar River falls between 14% and 45%, while groundwater extractions

Table 4
Results of the characteristic functions under non-cooperation and full cooperation for the scenarios of water management (10^6 €).

Water management scenarios	Coalitional arrangements		Normal	Mild drought	Severe drought	Very severe drought
Scenario 1	Non-cooperation	{INE}	132.0	119.2	109.3	100.5
		{IE}	58.3	51.7	43.5	35.0
		{C}	282.6	277.0	267.6	242.3
		{E}	74.7	37.2	33.0	33.0
		Total	**547.7**	**485.1**	**453.4**	**410,9**
	Full cooperation	**{INE,IE,C,E}**	**582.4** (6%)	**517.8** (7%)	**474.5** (5%)	**427.3** (4%)
Scenario 2	Non-cooperation	{INE}	132.0	119.2	109.3	100.5
		{IE}	58.3	51.7	43.5	35.0
		{C}	282.6	277.0	267.6	242.3
		{E}	74.7	37.2	33.0	33.0
		Total	**547.7**	**485.1**	**453.4**	**410.9**
	Full cooperation	**{INE,IE,C,E}**	**742.3** (36%)	**735.0** (52%)	**710.1** (57%)	**659.6** (61%)

Note: the percentage gain in benefits between full cooperation and non-cooperation is given in parenthesis.

increase up to 8 Mm^3. The benefit losses during droughts in the urban sector are below 14% in the worst-case scenario, because water provision is maintained with additional extractions from the Turia River and the Eastern La Mancha aquifer, but at higher costs.

4.1. Cooperative water management

Table 4 presents the values of the characteristic function under non-cooperation (baseline) and full cooperation for different drought conditions in the two scenarios of water management. Detailed results of the characteristic function of all coalitional arrangements under drought conditions for the two scenarios are presented in Tables A1 and A2 in the appendix.

The results suggest that full cooperative management of water in the JRB achieves the highest aggregate level of benefits for the two scenarios and all drought conditions. For *Scenario 1*, full cooperation among users improves benefits between 16 and 34 million € (4–7%) compared to non-cooperation. When a policy to protect the Albufera wetland is introduced in *Scenario 2*, full cooperation improves significantly benefits between 195 and 285 million € (36–61%) compared to non-cooperation. These improvements in benefits of full cooperation under both scenarios occur mainly because player IE transfers part of its water to players INE and E. Benefits under partial cooperation are always higher than under non-cooperation, but lower than under full cooperation.

The values of the characteristic functions of the JRB game under the different cooperative arrangements for the water management and climate scenarios show superadditivity compared to non-cooperation. This property is important because it indicates that the players have an incentive to cooperate. This incentive increases considerably when the environmental benefits provided by the Albufera wetland to society are accounted for in *Scenario 2*. Furthermore, it seems that partial cooperation between players IE, INE, and E is sufficient to maximize the benefits of the JRB and protect the Albufera wetland, and player C could be excluded from the game due to its minute contribution.[1] However, these results do not guarantee the acceptability of the cooperative agreement by the players nor its stability, and the likelihood of failure of cooperation remains. Therefore, to assure that the players remain cooperative, the reallocation of benefits among the players should be performed using the CGT solution concepts. These allocations are calculated in Section 4.2.

Fig. 2 presents the quantity of water flowing to the Albufera wetland under different cooperative arrangements and drought conditions for scenarios 1 and 2. Results indicate clearly that policy intervention to protect the Albufera wetland (*Scenario 2*) is better than non-intervention, securing always a fixed amount of water (138 Mm^3) flowing to the wetland. This amount is well above the minimum technical requirement of the Albufera wetland (60 Mm^3) set by the basin authority, and thus ensures a good ecological status. Moreover, cooperation without public intervention fails to provide the wetland with a minimum water threshold that could maintain its good ecological status (*Scenario 1*). Water inflows to the Albufera wetland in *Scenario 1* for severe and very severe droughts are far below the minimum requirement.

We find that achieving cooperation without policy intervention to regulate the Albufera wetland degrades the wetland. The reason is that most services provided by the Albufera wetland are public goods, and the private decision-makers in the river game have little incentive to conserve water and enhance the provision of such services. The Albufera wetland is linked to the IE player (ARJ and RB) which displays a lower value of water than the INE player (EM, CJT, and ESC). This is a common situation for environmental assets worldwide which are usually linked to subsidiary or low-value activities. In *Scenario 1*, benefit gains are achieved by reallocating water from player IE to player INE. Consequently, return flows to the wetland decline as drought severity intensifies producing the desiccation and degradation of ecosystems. Hence, both

[1] Player C is called a dummy player, using the Game Theory Jargon.

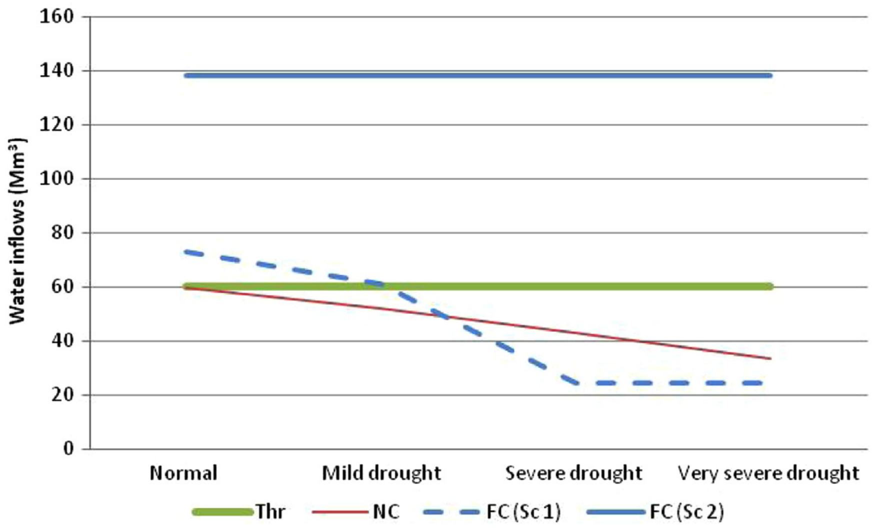

Fig. 2. Water inflows to the Albufera wetland under different coalitional arrangements and drought conditions for scenarios 1 and 2. Note: Thr=Threshold, NC=Non-cooperation, FC (Sc 1)=Full cooperation in *Scenario 1*, FC (Sc 2)=Full cooperation in *Scenario 2*. The threshold considered is 60 Mm^3 and it is calculated based on the minimum water requirements of the Albufera wetland and the percentage contribution of irrigation activities to water flowing to the wetland.

Table 5
Benefits by CGT solutions and non-cooperation in *Scenario 1*.

Climate scenarios	Players	Non-cooperation	Full cooperation		
			Shapley	Nash–Harsanyi	Nucleolus
Normal	INE	132.0	143.5	140.7	132.2
	IE	58.3	70.0	67.0	58.5
	C	282.6	282.7	291.3	282.6
	E	74.7	86.3	83.4	109.1
Mild drought	INE	119.2	130.8	127.4	121.4
	IE	51.7	64.5	59.9	82.2
	C	277.0	277.3	285.2	277.0
	E	37.2	45.2	45.4	37.2
Severe drought	INE	109.3	118.7	114.6	127.3
	IE	43.5	53.1	48.8	43.6
	C	267.6	269.5	272.9	270.6
	E	33.0	33.2	38.3	33.0
Very severe drought	INE	100.5	107.1	104.6	112.1
	IE	35.0	43.2	39.1	38.1
	C	242.3	243.8	246.4	244.1
	E	33.0	33.1	37.1	33.0

Table 6
Benefits by CGT solutions and non-cooperation in *Scenario 2*.

Climate scenarios	Players	Non-cooperation	Full cooperation		
			Shapley	Nash–Harsanyi	Nucleolus
Normal	INE	132.0	216.1	180.7	132.2
	IE	58.3	67.8	107.0	58.5
	C	282.6	282.8	331.3	282.6
	E	74.7	175.7	123.4	269.0
Mild drought	INE	119.2	209.6	181.7	291.4
	IE	51.7	84.1	114.2	93.9
	C	277.0	283.8	339.5	281.3
	E	37.2	157.5	99.7	68.6
Severe drought	INE	109.3	185.6	173.5	231.9
	IE	43.5	95.0	107.7	88.2
	C	267.6	303.9	331.8	312.3
	E	33.0	125.6	97.2	77.7
Very severe drought	INE	100.5	155.8	162.7	162.7
	IE	35.0	113.5	97.2	97.2
	C	242.3	283.8	304.5	304.5
	E	33.0	106.5	95.2	95.2

policy intervention and cooperation (*Scenario 2*) are needed for the full protection of the Albufera wetland under drought.

The comparison between the two scenarios indicates that public intervention to protect the Albufera through its inclusion in the cooperative agreement (*Scenario 2*), provides high incentives for cooperation. The result is a more sustainable use of water and substantial gains in basin benefits. A major policy implication from the analysis is that cooperation may have to be regulated by public agencies (the basin authority in this case) when scarcity is very high, in order to protect ecosystems and increase regional economic benefits.

4.2. Allocations of the cooperative benefits

The results of the different cooperative arrangements suggest that cooperative water management in the JRB yields higher benefits compared to non-cooperation. The challenge here is to allocate the benefits from cooperation

Table 7
Power and stability indexes in *Scenario 2*.

Cooperative solution	Power indexes of players (θ_i^a)				Stability index $\overline{\theta_a}$
	INE	IE	C	E	
Normal Flow					
Shapley	0.43	0.05	0.00	0.52	1.05
Nash–Harsanyi	0.25	0.25	0.25	0.25	0.00
Nucleolus	0.00	0.00	0.00	1.00	1.99
Mild drought					
Shapley	0.36	0.13	0.03	0.48	0.83
Nash–Harsanyi	0.25	0.25	0.25	0.25	0.00
Nucleolus	0.69	0.17	0.02	0.13	1.20
Severe drought					
Shapley	0.30	0.20	0.14	0.36	0.39
Nash–Harsanyi	0.25	0.25	0.25	0.25	0.00
Nucleolus	0.48	0.17	0.17	0.17	0.61
Very severe drought					
Shapley	0.22	0.32	0.17	0.30	0.27
Nash–Harsanyi	0.25	0.25	0.25	0.25	0.00
Nucleolus	0.25	0.25	0.25	0.25	0.00

among the players in a fair manner. The allocation of benefits is calculated using the different CGT allocation solutions. Then, the acceptability and stability of the benefit allocations are tested using the Core conditions (Eqs. (3)–(5)), the power index (θ_i^a), and the stability index ($\overline{\theta_a}$). Tables 5 and 6 show the allocated benefits to each player, based on the different CGT solutions.

Results of benefit allocations highlight that the preferred CGT solutions for the players vary, depending on the scenario of water management and the drought condition. The reason for these results lies in the properties of the CGT solutions. Player C does not contribute to any coalition in all management and climate scenarios but gains an equal share of benefit with Nash–Harsanyi. This is because Nash–Harsanyi allocates an equal incremental gain to each player based on its original benefit under non-cooperation, irrespective of its contribution to the coalition. Player E does not contribute either under *Scenario 1*, but gets an equal share with Nash–Harsanyi. Player E prefers mostly Shapley under *Scenario 2*, because it makes a contribution that is rewarded in the Shapley solution. Player INE prefers mostly the Nucleolus because this solution discourages the formation of partial coalitions that do not benefit him. These empirical findings on the preferred cooperative solutions for the players indicate the different interests of the players, and the difficulties to achieve a sustainable cooperative agreement at basin scale in the Jucar basin.

The analysis of the acceptability of the CGT allocations using the Core requirements indicates that the benefit allocations based on the Shapley and Nash–Harsanyi solutions for *Scenario 1* under different drought conditions satisfy only individual rationality (Eq. (3)) and the efficiency condition (Eq. (5)), but not group rationality (Eq. (4)). These allocations are not in the Core of the game, and they are not acceptable to the players. Therefore, the Shapley and Nash–Harsanyi solutions are not stable, and players may consider defection from the grand coalition to create partial coalitions. However, the Core requirements are satisfied for benefit allocations based on the Nucleolus solution, and they are acceptable to players in *Scenario 1*. For these reasons, the most stable cooperative solution in *Scenario 1* is the Nucleolus for all climate scenarios.

Under *Scenario 2*, the benefit allocations based on the three cooperative solutions satisfy the Core requirements, and since these allocations are in the Core they are acceptable to all players. So, theoretically there are no incentives for the players to leave the grand coalition in order to act individually or to participate in partial coalitions. However, players have different preferences over the

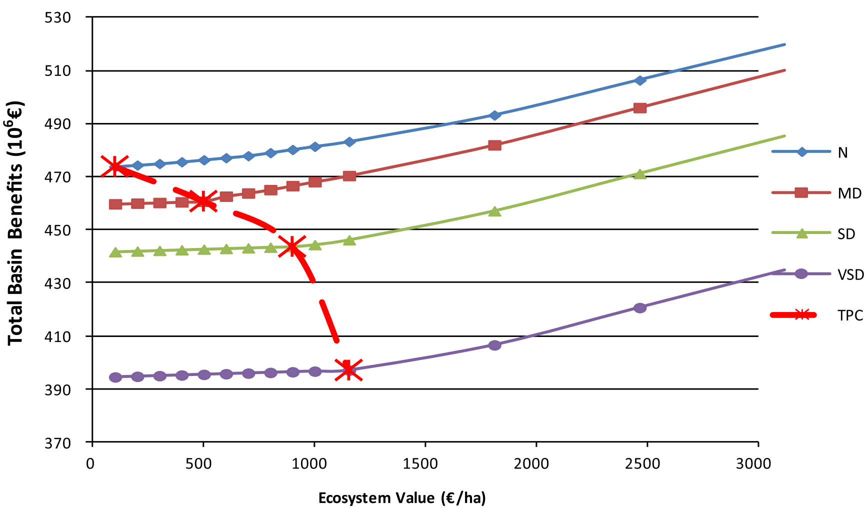

Fig. 3. Sensitivity analysis of the ecosystem value of the Albufera wetland. Note: *N*=Normal flow year, MD=Mild drought, SD=Severe drought, VSD=Very severe drought. TPC=Tipping point curve.

various allocation solutions. Therefore, there is a need to evaluate the stability of these solutions to find the best one in this scenario. Table 7 presents the power and the stability indexes for each cooperative solution in *Scenario 2*.

The stability indexes show that the most stable cooperative solution is the Nash–Harsanyi for all drought scenarios, although for a very severe drought scenario the Nucleolus achieves the same degree of stability as the Nash–Harsanyi. The least stable cooperative solution is the Nucleolus under normal flow, and mild and severe droughts, and the Shapley is the least stable under very severe drought conditions. Scrutiny of the stability indexes indicates that the stability of the grand coalition increases as drought severity intensifies. This means that the severity of drought is an incentive to act cooperatively.

The power indexes of players under the Shapley solution indicate that player E (the Albufera wetland) has the highest propensity to cooperate and stay in the grand coalition under all drought conditions, while player C (the cities) has the lowest propensity to cooperate and may disrupt the grand coalition unless improving its allocation. Under the Nash–Harsanyi solution, the power is distributed equally among the players, which means that the grand coalition is more likely to be stable. The Nucleolus solution shows that players E, IE, and INE display a high propensity to cooperate.

The results of the analysis of the acceptability and stability of the cooperative solutions suggest that the internalization of environmental damages in *Scenario 2* provides more stability to cooperation compared to *Scenario 1*. However, stability of cooperation under *Scenario 2* would likely be affected by the economic value of the ecosystem. A sensitivity analysis has been conducted in order to assess the results under *Scenario 2*, and their robustness to different economic valuation estimates of the Albufera wetland (Fig. 3). Results indicate that ecosystem value and drought condition affect the policy decision concerning the protection of the wetland. The tipping point curve in Fig. 3 shows the critical ecosystem values below which the Albufera wetland is excluded from the water sharing agreement (meaning no water is allocated to the wetland), and the game stability is reduced. The tipping point moves to higher values for the Albufera as drought severity intensifies because of the increase in the economic value of water (shadow price) to users.

5. Conclusions and policy implications

This paper develops a cooperative game theory framework in order to analyze the possibilities of cooperation over sharing water resources, and the options for protecting ecosystems in arid and semiarid basins under scarcity and drought. The framework was empirically tested in the Jucar River Basin (Spain), a typical highly stressed river basin in a semiarid region with acute water scarcity problems that are damaging valuable ecosystems.

Results indicate that drought damage costs in the Jucar River Basin are considerable. However, the cooperation of stakeholders through the right institutional setting reduces drought damage costs between 4% and 7%. When environmental damages are internalized through the inclusion of the wetland in the cooperative agreement, the cooperative results are more appealing, reducing drought damage costs by 52–61%.

Cooperative water management may be challenging in practice because of the strategic behavior of stakeholders and the high transaction costs of organizing collective action. Water agencies can promote cooperative management by creating different incentives for cooperation, such as taxes and subsidies, diversion thresholds, monitoring mechanisms, and technical advice. The role of these agencies is especially important in protecting ecosystems. Our empirical results indicate that cooperative management improves the economic benefits of water users but it may have little effect on ecosystems protection without additional incentives or regulations.

The cooperative game theory solutions and stability indexes examined in this paper provide information about the possibility for cooperation in the Jucar River Basin. This information could be helpful to reach an agreement to share water resources that could enhance private and social benefits. The empirical results suggest that cooperation is a feasible option, but the basis for cooperation is weak hindering the acceptability and stability of the cooperative agreement. However, the internalization of environmental damages provides more stability to the agreement, although it depends on the value of ecosystem.

The results highlight the fact that various cooperative solutions have different outcomes in terms of their acceptability by the players and their stability. This finding has important policy implication because it demonstrates the difficulties in selecting a mix of policy instruments that could address scarcity, and mitigate the negative impacts of droughts, and the risk of policy failure.

While the empirical analysis was performed using the Jucar Basin situation, our analytical framework is capable of providing meaningful results to any of the mounting cases of climate change-related water scarcity issues in any of the basins in arid and semiarid regions, including the ones mentioned in this paper. The inclusion of the strategic behavior of the parties involved in the drought mitigation policies is new to the policy analysis and would add an important aspect to the analysis of policy feasibility under scarce water situations.

Acknowledgments

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Appendix A

See appendix Tables A1, A2 and Fig. A1.

Table A1
Results of the characteristic functions under different coalitional arrangements and drought conditions in *Scenario 1* (10^6 €).

Coalitional arrangements	Players	Normal flow	Mild drought	Severe drought	Very severe drought
Non-cooperation	{INE}	132.0	119.2	109.3	100.5
	{IE}	58.3	51.7	43.5	35.0
	{C}	282.6	277.0	267.6	242.3
	{E}	74.7	37.2	33.0	33.0
	Total	**547.7**	**485.1**	**453.4**	**410.9**
Partial cooperation	{INE,IE}	190.6	181.9	170.3	150.2
	{C}	282.7	277.0	267.6	242.3
	{E}	74.5	33.0	33.0	33.0
	Total	**547.8**	**491.9**	**470.9**	**425.5**
Partial cooperation	{INE,C}	414.8	398.4	379.0	344.1
	{IE}	58.3	51.7	43.5	35.0
	{E}	74.7	37.2	33.0	33.0
	Total	**547.8**	**487.3**	**455.5**	**412.1**
Partial cooperation	{INE,E}	206.8	158.6	144.4	134.8
	{IE}	58.3	51.7	43.5	35.0
	{C}	282.6	277.0	267.6	242.3
	Total	**547.7**	**487.3**	**455.5**	**412.1**
Partial cooperation	{IE,C}	341.1	330.0	314.2	282.2
	{INE}	149.1	119.2	109.3	100.5
	{E}	74.8	40.8	33.0	33.0
	Total	**565.0**	**490.0**	**456.5**	**415.7**
Partial cooperation	{IE,E}	133.5	94.0	76.6	68.1
	{C}	282.6	277.0	267.6	242.3
	{INE}	132.0	119.2	109.3	100.5
	Total	**548.1**	**490.2**	**453.5**	**410.9**
Partial cooperation	{C,E}	357.4	314.2	300.6	275.3
	{INE}	132.0	119.2	109.3	100.5
	{IE}	58.3	51.7	43.5	35.0
	Total	**547.7**	**485.1**	**453.4**	**410.8**
Partial cooperation	{INE,IE,C}	473.3	459.5	441.5	394.3
	{E}	74.5	33.0	33.0	33.0
	Total	**547.8**	**492.5**	**474.5**	**427.3**
Partial cooperation	{INE,IE,E}	299.8	240.8	203.3	183.2
	{C}	282.6	277.0	267.6	242.3
	Total	**582.4**	**517.8**	**470.9**	**425.5**
Partial cooperation	{INE,C,E}	489.5	435.6	412.0	377.1
	{IE}	58.3	51.7	43.5	35.0
	Total	**547.8**	**487.3**	**455.5**	**412.1**
Partial cooperation	{E,C,IE}	416.1	370.9	347.2	315.2
	{INE}	132.0	119.2	109.3	100.5
	Total	**548.1**	**490.1**	**456.5**	**415.7**
Full cooperation	**{INE,IE,C,E}**	**582.4** (6%)	**517.8** (7%)	**474.5** (5%)	**427.3** (4%)

Note: the percentage gain in benefits between full cooperation and non-cooperation is given in parenthesis.

Table A2
Results of the characteristic functions under different coalitional arrangements and drought conditions in *Scenario 2* (10^6 €).

Coalitional arrangements	Players	Normal	Mild drought	Severe drought	Very severe drought
Non-cooperation	{INE}	132.0	119.2	109.3	100.5
	{IE}	58.3	51.7	43.5	35.0
	{C}	282.6	277.0	267.6	242.3
	{E}	74.7	37.2	33.0	33.0
	Total	**547.7**	**485.1**	**453.4**	**410.9**
Partial cooperation	{INE,IE}	190.6	181.9	170.3	150.2
	{C}	282.7	277.0	267.6	242.3
	{E}	74.5	33.0	33.0	33.0
	Total	**547.8**	**491.9**	**470.9**	**425.5**
Partial cooperation	{INE,C}	414.8	398.4	379.0	344.1
	{IE}	58.3	51.7	43.5	35.0
	{E}	74.7	37.2	33.0	33.0
	Total	**547.8**	**487.3**	**455.5**	**412.1**
Partial cooperation	{INE,E}	389.6	312.3	190.0	134.8
	{IE}	58.3	51.7	43.5	35.0
	{C}	282.6	277.0	267.6	242.3
	Total	**730.5**	**641.0**	**501.1**	**412.1**
Partial cooperation	{IE,C}	341.1	330.0	314.2	282.2
	{INE}	132.0	119.2	109.3	100.5
	{E}	74.8	40.8	33.0	33.0
	Total	**547.9**	**490.0**	**456.5**	**415.7**
Partial cooperation	{IE,E}	166.7	157.5	79.1	68.1
	{C}	282.6	277.0	267.6	242.3
	{INE}	132.0	119.2	109.3	100.5
	Total	**581.3**	**553.7**	**456.0**	**410.9**
Partial cooperation	{C,E}	358.6	314.2	300.6	275.3
	{INE}	132.0	119.2	109.3	100.5
	{IE}	58.3	51.7	43.5	35.0
	Total	**548.9**	**485.1**	**453.4**	**410.8**
Partial cooperation	{INE,IE,C}	473.3	459.5	441.5	394.3
	{E}	74.5	33.0	33.0	33.0
	Total	**547.8**	**492.5**	**474.5**	**427.3**
Partial cooperation	{INE,IE,E}	459.7	449.5	353.1	283.4
	{C}	282.6	277.0	267.6	242.3
	Total	**742.3**	**726.5**	**620.7**	**525.7**
Partial cooperation	{INE,C,E}	672.3	636.9	540.7	386.5
	{IE}	58.3	51.7	43.5	35.0
	Total	**730.6**	**688.6**	**584.2**	**421.5**
Partial cooperation	{E,C,IE}	449.3	439.4	422.6	389.5
	{INE}	132.0	119.2	109.3	100.5
	Total	**581.3**	**558.6**	**531.9**	**490.0**
Full cooperation	**{INE,IE,C,E}**	**742.3** (36%)	**735.0** (52%)	**710.1** (57%)	**659.6** (61%)

Note: See note to Table A1.

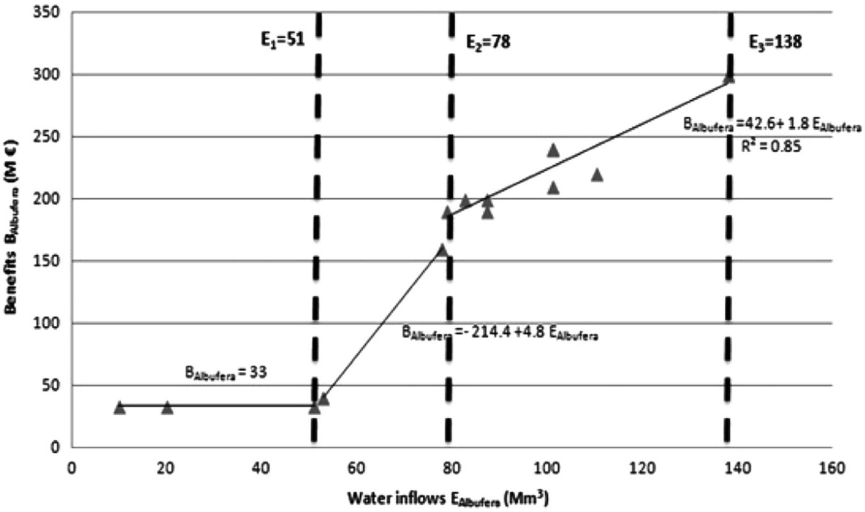

Fig. A1. Environmental benefit function of the Albufera wetland.

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