Mohamed Taher Kahil (IIASA, Austria), Prof. Ariel Dinar (University of California) & Jose Albiac (CITA, Spain)

La Albufera wetland in the Jucar Basin.
Source: Jose Albiac

Global water resources face new challenges in the coming decades that entail a renewed role for water policy analysis. Scarcity, growing populations, and massive water development projects have led to keen competition over water resources. Climate change is expected to further reduce the availability of water resources and increase the variability in water supplies in some regions, especially in arid and semiarid basins. While emerging social demands for the protection of water dependent-ecosystems are increasing competition for already scarce water resources.

Under these circumstances, the efficient and fair allocation of water among users is becoming a major challenge for water authorities. New water allocation mechanisms based on the involvement of stakeholders are needed.

Several policy responses have been suggested in the literature to address climate change impacts. However, the existing literature usually overlooks one important aspect that determines the success of policy interventions; the strategic behavior of the individual stakeholders. The inclusion of strategic behavior is essential for assessing the acceptability and stability of policy interventions aimed at promoting the joint management of water resources. In a recent study, Kahil et al. (2015) have addressed this gap by developing a cooperative game theory (CGT) framework at a basin scale[1]. Several CGT sharing mechanisms and stability indexes have been used to find efficient and fair allocations of water and income among river water users under various climate change scenarios.

CGT and water resources

The use of game theory to address water management problems has been growing since the pioneer application by Ransmeier (1942) to an investment cost allocation problem in the Tennessee Valley Authority[2]. In particular, 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 water projects, efficient sharing of river systems, joint management of aquifers, pollution control, operation of hydropower facilities, and resolution of transboundary water conflicts[3].

CGT deals with games in which stakeholders (players) choose to cooperate by forming coalitions and sharing fairly the benefits from those coalitional arrangements. CGT favors agreements that include all possible players (grand coalition) and it provides several benefit sharing mechanisms. These mechanisms reveal different possible societal understanding of fairness. The purpose of CGT is to find the incentives for cooperation among stakeholders in order to achieve economically 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 promotes acceptable and stable cooperative outcomes.

Application of CGT to basin management in Spain

A CGT framework has been developed and applied to a typical semiarid basin in Southeastern Spain, the Jucar basin, which is a good case for studying the strategic behavior of stakeholders and policies to address climate change impacts. The Jucar River is under severe stress with acute water scarcity, and substantial ecosystem degradation. The framework consists of a three-step process.

First, an optimization model is developed to assess the outcomes of alternative water allocation policies: non-cooperative policy, cooperative policy 1 which disregards the environmental benefits provided by an important aquatic ecosystem in the basin (the Albufera wetland), and cooperative policy 2 which accounts for the environmental benefits provided by the Albufera wetland. Cooperative policies aim to allocate water efficiently among the various players.

If additional benefits are obtained from the cooperative policy interventions compared to non-cooperation, the next step consists of *redistributing* the additional benefits among the cooperating players using CGT sharing mechanisms (e.g., Shapley Value, Nash-Harsanyi, Nucleolus), and testing whether these redistributions are acceptable for the players or not. *Acceptability* is defined using the so-called Core conditions of a cooperative game, which compare the benefits obtained by each cooperating player under the grand coalition to what each player can obtain under non-cooperation, or by participating in partial coalitions that include some and not all the players in the game.

Policy interventions		Players[**] INE	IE	C	E	Total	Is solution acceptable?[†]	Most stable solution[††]
Non-cooperative policy		100.5	35	242.3	33.0	410.8	-	-
Cooperative policy 1[*]	Shapley	107.1	43.2	243.8	33.1	427.2	No	Nucleolus
	Nash-Harsanyi	104.6	39.1	246.4	37.1	427.2	No	
	Nucleolus	112.1	38.1	244.0	33.0	427.2	Yes	
Cooperative policy 2[*]	Shapley	155.8	113.5	283.8	106.5	659.6	Yes	Nash-Harsanyi, Nucleolus
	Nash-Harsanyi	162.7	97.2	304.5	95.2	659.6	Yes	
	Nucleolus	162.7	97.2	304.5	95.2	659.6	Yes	

Source: Kahil et al. (2015).
[*] Three CGT sharing mechanisms based on different notions of fairness are used: Shapley value, Nash-Harsanyi and Nucleolus.
[**] The main water users in the Jucar Basin are classified into four players with similar characteristics: irrigation districts not linked to the Albufera (INE); irrigation districts linked to the Albufera (IE); the cities (C); and the Albufera (E).
[†] Acceptability is tested using the Core conditions.
[††] Stability is tested using the Loehman power index.

Table 1. Benefits (M□), acceptability and stability of policy interventions under a very severe climate change scenario. Source: Kahil et al. (20150

The last step consists of testing the *stability* of the acceptable cooperative solutions using some of the methods suggested in the CGT literature. This is important because the acceptability of a solution does not guarantee its stability as some players may find it relatively unfair compared to other solutions or to what other players have obtained. They might threaten to leave the grand coalition, and act individually or form partial coalitions because of their critical position in the grand coalition. 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.

Results and policy implications

The results of this study provide clear evidence that achieving cooperation reduces climate change impacts on water resources (Table 1). 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. This is the case in the scenario of cooperative policy 2, when environmental damages are internalized through the inclusion of the wetland in the cooperative agreement.

Additionally, the results highlight the fact that various cooperative solutions have different outcomes in terms of their acceptability to the players and their stability. This finding has important policy implications, because it demonstrates the difficulties in selecting a mix of policy instruments that could address climate change impacts, and the risk of policy failure.

Finally, the results show the importance of incorporating the strategic behavior of water stakeholders through the use of CGT tools for the design of acceptable and stable basinwide climate change adaptation policies.

References:

1. Kahil, M.T., A. Dinar and J. Albiac (2015). Cooperative water management and ecosystem protection under scarcity and drought in arid and semiarid regions. Water Resources and Economics (2015), http://dx.doi.org/10.1016/j. wre.2015.10.001.
2. Ransmeier J. S. (1942). The Tennessee Valley Authority: A case study in the economics of multiple purpose stream planning. Nashville: Vanderbilt University Press.
3. Dinar, A. and M. Hogarth (2015). Game theory and water resources: Critical review of its contributions, progress and remaining challenges. Foundations and Trends in Microeconomics 11 (1-2): 1-139, http://dx.doi.org/ 10.1561/0700000066.

Mohamed Taher Kahil is a research scholar at the Water Program of the International Institute for Applied Systems Analysis (IIASA-Austria), working on the evaluation of water policies and management, hydro-economic modeling, and impact assessment of climate change and water scarcity. Ariel Dinar is a professor of environmental economics and policy at the School of Public Policy, University of California, Riverside. He teaches and conducts research on issues related to water economics, climate change economics, regional cooperation, and international water management. Jose Albiac is a researcher at the Agrifood Research and Technology Center (CITA-DGA) in Zaragoza, Spain. His research specializes in environmental and natural resource economics, environmental and agricultural policies, water management, water scarcity and droughts, irrigation, groundwater and ecosystems protection, nonpoint pollution, and climate change.