Supporting collective decision-making processes in case of water management

Reflections on the interaction space

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1 The joint management of common-pool resources

The distribution and the management of a limited and shared resource is a complex challenge (Ostrom, 2011). One of the central issues to public policies on common-pool resources is the balance between the allocation of a limited resource and its preservation. Water management faces numerous problems such as the disparity of interests, multiple decision-makers interacting, complex and inadequate networks of governance and distribution, various socio-political circumstances, intensive socio-economic development (Daniell et al., 2010), and increasing severity of environmental stressors such as climate change which impact on the water cycle (Moore et al., 2014). Furthermore, drought-induced water shortage is a global threat affecting societies, economies, and ecologies (van Duinen et al., 2015). Drought phenomena are significant drivers of the character and evolution of natural-human systems, leading to a radicalization of negative conditions, increasing conflicts and exasperating the interactions occurring in order to share a limited resource. Thus, managing water resources is a major challenge for policy-makers given the multiple stresses impacting water resources worldwide (Nair and Howlett, 2015). Frequently, these impacts manifest in the form of conflicts (Giordano et al., 2017; Giordano et al., 2015; Madani et al., 2014) especially under water shortage conditions (e.g., UNESCO, 2002; Sneddon and Fox, 2006; FAO Water Report, 2012). For instance, an increasing level of conflict between different water users and uses is observed in water management in the Mediterranean basin, which is facing a twofold problem (Giordano et al., 2007; Portoghese et al., 2013). On the one hand, the spread of intensively irrigated agricultural areas is leading to a dramatic increase in water demand. On the other hand, the Mediterranean region is characterized by water shortage problems as a result of its climatic conditions (Iglesias et al., 2007). The rising imbalance between water demand and water availability is leading to the conflict for the current water pricing system to a critical level.

Consequently, this chapter is based on Ostrom's claim (Ostrom, 1990) and assumes that using a water market as the singular way to allocate resources could lead to inequalities and to depletion. Given a geographically highly distributed common-pool resource (CPR), used by several competing users and owned by no one, water requires management methods and tools to support the detection, analysis, and reduction of conflicts through a non-binding mercantile business.

It is common in practice to face situations in which users are required to reduce uses of a scarce common resource in order to increase their long-term benefits (Madani and Dinar, 2013). A common-pool resource (CPR) is defined as a resource system whose yield is subtractable and makes the exclusion of potential appropriators or limitation of the existing users' rights nontrivial, but not necessarily impossible (Ostrom, 1990; Ostrom et al., 1994). Two decades of research into the management of CPRs suggests that, under particular conditions, local communities can manage shared resources sustainably and successfully (Ostrom, 1990; Hess and Ostrom, 2003; Pluchinotta et al., 2015). These findings are often considered somehow revolutionary, in that they were able to challenge the long-held belief in the well-known Hardin's "tragedy of the commons" (Hardin, 1968). In fact, early works expected all CPR users to show non-cooperative and competitive behaviours that make the tragedy of the commons (Gordon, 1954; Hardin, 1968) inevitable. The argument was that within a CPR dilemma, parties always base their actions on individual rationality (as opposed to rational group choices), which negatively affect all users eventually (Ostrom, 2010; Madani and Dinar, 2013). When decision-agents are completely independent from each other, interacting solely by the fact that they use the same resource, the standard problems of overexploitation, and free-riding arise. Instead, as Ostrom argued, the tragedy is not inevitable when a shared resource is at stake, provided that communities interact and operate in a collective way avoiding the market rules constraints (Ostrom et al., 2012). Ostrom (Ostrom, 1998) recognized the need for expanding the range of rational choice models to be for studying collective actions. In her view, most previous models failed to capture the reality of a decision-making process, which might be affected by different factors such as communication, interactions, trust, learning, and norms (Madani and Dinar, 2013). Indeed, scholars suggest that the CPR users have the potential to escape the resource depletion trap through developing cooperative institutions and collective actions that can enforce sustainable exploitation and development (Madani and Dinar, 2013; Castillo and Saysel, 2005).

The above-mentioned issues generate the need to enhance decision-aiding practices within a collective framework, where multiple decision-makers are deeply involved. When stakeholders are not involved in the development and evaluation of the alternative course of actions, the outcomes of the decision-making process become controversial and could generate strong opposition (Faludi, 1985; Borri et al., 2013, 2015). In this context, collaborative decision processes with public actors and public objects generate unpredictable scenarios because of the great variety of objects and of the competing intervening actors (Tsoukiàs, 2007, 2008). CPR management policies are intended to regulate the behaviour of individual decision-agents. The agents themselves are inter-dependent in performing their tasks, so that any choice will influence and be influenced by the choices of the other actors (Brock and Durlauf, 2001). While these interactions among a diversity of decision-makers may contribute to the development of beneficial adaptive behaviours, they can also provoke unexpected and sometime undesirable reactions, since the choices of an individual agent may not necessarily be aligned with the viewpoints, expectations or possibilities held by the others (Giordano et al., 2017; Pluchinotta et al., 2018, 2019). This later situation can result in lack of legitimacy of the decision. The lack of legitimation to act, often leads to dysfunctional dynamics (i.e. unexpected evolution of the system dominated by certain interaction patterns or by actions that are delayed or by shifts in feedback loops). As a result, the role of decision tools in the context of CPR management decision processes is changing, since it is widely recognized that there should be no single decision-maker, but rather a process of debate that should take place among different agents (Guimarães Pereira et al., 2005). The decision tools should be capable of capturing the decision-making as it is, not as it should be. They should be focusing on the limited cognitive capabilities of human decision-agents, i.e., the bounded rationality described by Simon (1957). This requires a dynamic decision-aiding tools able of integrating the different problem frames held by the decision- makers in order to: (i) clarify the differences among those frames; (ii) support the creation of a collaborative problem structuring process; (iii) provide shared platforms and interaction spaces; and (iv) reconstruct the connections between these platforms and engaged interactions. Existing structures such as the action arena (Ostrom, 1986) and the interaction space (Ostanello and Tsoukiàs, 1993) allow studying how the establishment of local regulations and rationalities, may help escaping from market regulations and facilitating stakeholders interactions in the case of CPR.

Starting from these premises, this chapter discusses the system dynamics model (SDM) built in Pluchinotta et al., 2018 to explore the interactions and interdependencies between various stakeholders, in order to support collaborative decision process for the water management of the agricultural system in the Apulia region (Italy).

2 Interactions spaces

According to the assumptions made in the previous paragraph, there is a deficiency of adequate methodologies for problem formulation and objective setting in supporting decision-making processes with multiple stakeholders. Decision aiding in the multi-stakeholder domain focuses on providing an analyst with methodological support that allow it to facilitate stakeholder groups to structure and exchange views. These exchanges may span focal areas ranging from problem formulation and objective identification to final recommendations or “choices” (Daniell, 2012; Dionnet et al., 2013). This issue is faced by the concepts of action-arena (Ostrom, 1986), interaction space (Ostanello and Tsoukias, 1993). These formal structures support interactions and enable the establishment of local rules and rationalities (Pluchinotta et al., 2018). Specifically, the action arena can be used to analyse, predict and explain behaviour (Ostrom, 1986) and it contains action situation, actors, and rules (Polski and Ostrom, 1999).

Action arena was developed in the Institutional Analysis and Development (IAD) framework to analyse collective choice processes. This structure has mainly been applied to analyse static representations of social systems and the evolution of rules (formal and informal) over time may be analysed by comparing different representations (Pahl-Wostl et al., 2002). Action arena is a social space where individuals interact, exchange goods and services, solve problems, dominate one another, or fight (Ostrom, 1986). The key idea of Ostrom is to understand a society as a structure of interconnected and/or nested action situations and involved participants (Ostrom et al., 2012). Participants in action arenas interact as they are affected by exogenous variables and produce outcomes that in turn affect the participants and the action situation (Pahl-Wostl, 2002). The structure of an action arena can be described and analysed by using a common set of variables. Ostrom (1986, 1999) identified seven variable sets that define the action situation used to identify regularities of human actions, in order to evaluate patterns of interactions that are logically associated with behaviour, and outcomes from these interactions. An action arena combines the action situation, which focuses on the rules and norms, with the participants who bring with them their individual preferences, skills, and mental models (Anderies and Janssen, 2013). The action arena analyse the rules-in-use, the operating rules that are commonly used by most participants rather than rules that can be articulated but are not widely observe. Ostrom (1986, 2005, 2007) distinguishes seven different types of rules that affect the structure of an action situation: position rules, boundary rules, scope rules, authority rules, aggregation rules, information rules, and payoff rules. Understanding the formal and informal rules that affect behaviour in the action arena is best suited to policy tasks that involve developing new policy initiatives or comparing alternative policy designs.

The Ostanello and Tsoukiàs' (1993) interaction space (IS) is a collaborative space where a meta-object is identified as the articulation of the participants' problem representation. Similar to the action arena, the IS can form the basis for further collective discussion and decision-making. ISs are virtual informal spaces where decision-makers can operate on the understating and resolution of a problem. In fact, according to Mazri (2007) IS is a formal or informal structure governed by a number of rules and aimed at providing a field of interaction to a finite set of actors. The concept of IS has been introduced in order to represent a meeting structure of subjects from different organizations, an informal and abstract structure that allows exchange and communication condition by a public confrontation. A set of elements (participants A, objects O, and resources R) and an architecture of relations S on this set constitute an interaction space model. The definition of primary elements sets carries out the identification of the IS state and the multi-step procedure that enables the building of the IS is explained in Ostanello and Tsoukiàs (1993). The identification of the IS state allows the analyst to indicate some organizational/political features that the acting system has assigned to the IS. What is more, the identification can generate hypotheses on the coherence of future actions that a participant could be willing to undertake. Such a formal model, even if simplified to just a few theoretically important variables, can provide a useful basis for understanding decision dynamics with multiple stakeholders. It therefore provides a conceptual framework for the development of decision-aids aiming to guide the evolution of the IS in a favourable direction (for a given client). It is expected that using IS allows the analysts to deal with different participants, formalizing a formal structure and consequently, the participants in a decision process can discuss. This process can improve transparency of the process and increases participation. The construction of this artefact should allow, on the one hand, the clients to recognize their position within the decision process for which they asked the decision support. On the other hand, it would allow the analyst to understand the problem statement within the decision process and the interconnected networks in which decision-makers operate. In conclusion, the IS is a descriptive and explicative model that could support collaborative decision-process.

3 Critique of the interaction space

The management of a CPR is defined by an interconnected network that exhibit high levels of interaction, conflict, and uncertainty due to limited information, to bounded rationality, to the disparities in meaning for particular issues and to the discrepancies in the way in which the situation is interpreted. Hence, the use of the actual structure of IS has several drawbacks.

The IS is an evolving structural idea, it nevertheless remains a static picture of the problem that allows to explain the meaning of the behaviour of actors. However, the interactions among decision-makers are not static. They are influenced by the boundary conditions. Moreover, the implementation of policies, both as internal and as external drivers, can trigger changes in the structure of the interactions. Changes in IS (e.g. involvement of other actors with different objects and resources) can be also non-immediate and indirect. Thus, the analysis of the IS requires tools and methodologies capable of accounting for such a dynamic nature.

As Ostrom suggested for the action arena, the IS also lacks detailed analyses of rules, strategies, and actions that can allow the analyst to better understand how an IS model for a stakeholder is constructed and its interdependencies with other ones. In a multi-stakeholder decision-process, each decision-maker has its own frame (vision) of the problem, which leads him to have a personal rational model and to, consequently, decide his own plan of actions in order to achieve his objectives. It is possible to assert that each agent has a personal view of the IS configuration and that often agents are not conscious of the existence of the other agents or of the complete sets of objectives and resources. Besides, these perceptions are personal and they evolve with exchanging of information and changing surrounding conditions.

Intuitively, the idea of an IS is structured and reasonable, but the empirical evidence has shown the lack of operational abilities and formal support in complex case studies. The IS is a descriptive approach and in its current structure does not have collective features for understanding interactions. Thus, it is not able to explain the complexity of debates in its entirety and to fulfil the need of a prescriptive model. The introduction of dynamism and the simulations of future scenarios could improve the model.

4 The structure of the dynamic interaction space

In this chapter, a dynamic interaction space (DIS) has been built, highlighting the operative criticalities showed before. The DIS aims to support a dynamic decision-process where a finite set of decision-makers is involved, providing a field of interaction. It is a collaborative space in which the interactions (real or virtual) among the decision-makers take place and where their frames can change in a prepositive way. It is an informal structure governed by a number of rules, in which several stakeholders become involved, both intentionally and not. Such a structure enables the establishment of local regulations and rationalities, escaping for instance from market regulations in the case of commons goods and facilitates communication and agent interactions with the analysis, the explanation and the prediction of behaviours. This framework can be used both to integrate and legitimate behaviour as well as to reduce complexity. The DIS model allows the analysts to identify a joint set of objectives and to create a shared problem definition used to generate new knowledge. It is important to understand the dynamics of a system in order to extract critical functioning parts and attempt to build a model that captures its essence by making assumptions to account for external variables.

The DIS model is defined by sets of agents, objects, resources, and a structure of relations that develop between these sets. Additionally, it also contains selected rational models allowing the IS to evolve. The DIS structure in detail: A represents the set of involved agents in the DIS. The agents can be considered as individuals or organizations. Such a position can be clarified via the relationships that each participant has with both other intervening agents as well as resources, concerning some object. In this regard, it is important to identify a hierarchy between them to understand how the existing situation can evolve. Each agent is defined by a n-tuple (r,τ,γ) where the type τ and the role r are agent's attributes, while γ is an element of the set of goals Γ.

The general set O of objects is composed of three different classes of entities: abstract objects concerning preoccupations and needs of agents, modelling objects created for the modelling part, and dynamic objects that represent the point of evolution of the system for simulations. A dynamic object provokes transformations in the model and it can be measured (e.g. a modification of water volume employed or requests). The set of objects is derived from surveys and interviews with expert-agents and stakeholders.

R is a set of commitments concerning the objects with which the participants are involved in DIS. The resources can be available, used, needed, and searched for. Every participant may show a different capacity to use his own resources and to activate new ones.

Under the hypothesis of agents driven by a subjective rationality, T represent the set of agents' rational behaviour models in a specific DIS configuration. Several agents operating with their own locally rational decision rules (intended rationality and not casual rationality) characterize these decision environments. T regulates the nature and dynamics of action situations. Thus, the formalization of T, made by the analyst through the different possible approaches (e.g. linear or non-linear programming, game theory, system dynamic, multi-agent system, etc.), can be adapted to each case study, depending on the modelling needs. T supplies the dynamism to the system concerning a timeline, helps in the simulation building and in the definition of the rules in use.

As in the IS, a set of relations characterizes the DIS. The relations are (i) a binary relation of projection or evocation that explain the hierarchy between objects (e.g. the relation between dynamic objects allows to understand the possible evolution of the system and it can help in modelling and simulation); (ii) a binary relation of attributes defined between agents and objects. Each object is linked to at least one agent and vice versa; (iii) a ternary associative relation defined between A, O, and R. It is symmetrically associated with any resource r∈R which could be used or searched for by an agent concerning an object.

5 Agricultural water management in the Apulia Region (Italy)

Starting from these premises, a methodology capable of analysing the DIS and to support policy analysis in a collaborative water management has been developed using a system dynamic model (SDM). For details see Giordano et al., 2017 and Pluchinotta et al., 2018, while this section summarizes and discusses the main findings related to the management of a CPR and the DIS. The process goes through a multi-step procedure, adapted from Ostanello and Tsoukiàs (1993) and ensures the coherent overall methodology. The construction of the DIS starts with the identification of objects and potentially involved agents with their attributes. Afterwards, the next stage is to define the hierarchy and relations between them. The consecutive steps involve the definition of resources and their relations to objects and agents. Finally, the dynamic evolution of the interaction space is simulated using the SDM described in Pluchinotta et al., 2018. The case study deals with water management in agricultural systems in the Apulia region (Southern Italy). Specifically, the SDM has been applied to analyse the interactions between multiple decision-makers concerned by the groundwater (GW) management and protection, as well as between them and the physical and economic elements. Within the case study analysed, the stakeholders are farmers, the water manager, and the Regional Authority. The water manager, Consortium of Capitanata, has to deal with the scarcity of water of the region and with the request of water from each farmer. Farmers have to share the same resource.

Each farmer is expected to choose the right cropping plan in order to maximize his profits. Farmers' decisions also concern the selection of the main source of water for irrigation such as GW or fresh water provided by the Consortium. The GW overexploitation brings about social and environmental problems and the regional authority, the Apulia Region, needs to protect groundwater quality and to keep a high level of productivity of the agricultural sector. Accordingly, the SDM is based on the analysis of the differences in problem understating and personal understanding of the DIS among the interested/involved decision-makers (for details, Giordano et al., 2017; Pluchinotta et al., 2018, 2019). The SDM has been used in order to simulate the evolution of the DIS. The basic assumption is that not all the decision-makers are interested/forced to enter in the DIS in the early stages of the action implementation. Nevertheless, the feedback loops and delays governing the evolution of the system could lead to unexpected impacts, forcing other decision-makers to join the DIS. We assume that a decision-agent is forced to enter in the DIS when her/his objects are impacted by the implemented action.

In detail, for the aim of this chapter is interesting to discuss about the business-as-usual scenario. Briefly, at the beginning of the scenario simulation, the water available for irrigation is enough to satisfy the crop requirement. However, due to the favourable conditions of the market, the farmers have a strong preference for the irrigated agriculture. Moreover, the farmer prefers the water provided by the Consortium, because it is considered of a better quality compared to the GW. Afterwards, due to the drought conditions, the Consortium implements a Water Conservation Policy, reducing the amount of available water for each farmer. In these conditions, the farmer decides to use the GW in order to balance the irrigation budget (water requirement minus water available). Due to the lack of legitimacy for the Consortium's decision and the lack of control by the Regional Authority, the farmer perceives the GW as an almost unlimited and easily accessible resource, resulting in an ever-increasing pressure on GW. It is interesting to note that the increasing of irrigated areas provokes an increasing of the agricultural productivity. Finally, due to the reduction of water taken for irrigation caused by the Water Conservation Policy, the consortium budget is strongly negative.

The SDM allows observing the evolution of the interactions among the decision-makers in the DIS. One of the first observations is that different involved agents are interested in different configurations of the DIS. Therefore, some decision-makers have passive behaviour, as their goal is not directly linked to a particular DIS configuration. The actions of the initial active agents influence the involvement and the decision-process of the other agents. For example, at the beginning in the DIS there are only farmer agents that are making decisions regarding their crop plan (e.g. increasing or decreasing irrigated areas).

At this point, the Consortium is not interested in entering into the DIS configuration. Zooming in at a different scale, the farmers are driven by external input (e.g. environmental conditions and water price). Their multiple decisions influence the interest of the Consortium. In consequence, in the case of water scarcity the Consortium decides to enter in the DIS when their budget is decreasing, because farmers are using mainly GW. The Consortium enters the DIS in order to defend their own economic interest. Otherwise, during years of water abundance the Consortium has no interest of entering. Within the DIS configuration, the Regional Authority is generally not interested in being an active element. Their main objects are the environmental protection, the increase of agricultural productivity and the improvement in the management of the irrigation water system for decreasing GW overexploitation for which they mainly use legislative constraints resources. The Regional Authority does not recognize the role of the feedback loop between the Consortium and the farmers' decisions. Hence, it is not interested in entering the DIS. In this specific scenario, each decision-agent presented above has a limited understanding of the DIS. This drives them to make decisions based on his/her own understanding, therefore ignoring the possible actions of other involved agents. The difference in perception and the non-interaction has been identified as a limit for the suitable evolution of the DIS (Giordano et al., 2017). The SDM displayed how the limited understanding of the DIS affects the actions followed by each class of decision-makers and, finally, how it could lead to reduce legitimacy. For example, (i) if the Regional Authority ignores the role of the economic drivers it will not create synergies between economic policies (subsidies) and GW protection policy; (ii) if the Regional Authority neglects the possibility of GW use in spite of the law (illegal pumping), it will not consider the failure possibility of a GW protection policy; (iii) if the Consortium neglects the existence of GW as an alternative water source, it will define the water conservation strategy without considering the actual impact on the whole water resources (surface and GW); (iv) if the Consortium ignores the role of economic drivers and the importance of the information delay, it will not improve the timeliness of the information sharing with the farmers (see Giordano et al., 2017 and Pluchinotta et al., 2018 for details).

In conclusion, an improved understanding of the DIS is an important element to make the decision-agents aware of the role played by each other, in order to support collaborative decision-processes for CPR management, aiming to identify creative solutions.

6 Conclusions

The water management system is a set of physical and abstract networks where decision-agents operate and many interactions take place between decision-makers, either directly or via the environment and the use of the resource. Specifically, ignoring the water management complexity and neglecting the role of the feedback mechanisms could hamper the ability to manage the system itself (Giordano et al., 2017). For this reason, in this work, challenges in water management have led to the development of methods for enhancing the understanding of interactions and interdependencies in collaborative decision-making processes for an improved CPRs management. In our case study, the SDM was used as a platform for modelling multiple decision-makers, in order to explore and simulate interactions and hierarchies in the DIS. In this regard, the proposed SDM is aimed to represent the existing situation in our case study, understanding the structure and the macro behaviour of a system through its internal decision sub-models (see Pluchinotta et al., 2018). The SDM has the objective to model the architecture of interactions between involved agents in the DIS, formalizing the behaviours of users and the consequences of their actions on the system. Furthermore, the developed SDM was used also to facilitate the identification of the neglected interactions and agents' different perceptions of the DIS, in order to combine hydrological, socioeconomic, and behavioural drivers of water use. As described further in the text, the SDM demonstrated how the decisions taken by each agent referring exclusively to her/his own individual understanding of the DIS provoked unexpected reactions by the others, leading the system towards unsustainable evolution trajectories. Thus, the model allows us to test the importance of local interactions between farmers and water manager and Regional Authority, and to provide a tool to help the authorities in their search for a socially acceptable way of managing demand to protect the resource in the observed field. Specifically, the developed methodology could be used to bring the decision-makers to interactively construct a shared understanding of the GW management issues during drought phenomena. Of course, the research effort is not aimed at providing the optimal solution for water allocation, price decision, and cropping plan. Instead, the goal is to show to the decision-makers the possible consequences of their action's choice, according to different criteria: economic drives, vision disparities between agents, water savings. The results of this work could be used as a starting point for future research activities dealing with the complexity of water resources management and policy design (e.g. Pluchinotta et al., 2019).

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