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Ambiguity in problem framing as a barrier to collective actions: some hints from groundwater protection policy in the Apulia Region

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Ambiguity in problem framing as a barrier to collective actions: some hints from groundwater protection policy in the Apulia Region

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Keywords: Problem framing; Ambiguity analysis; Policy analysis; Causal Loop Diagram.

1 Introduction

In many regions of the Mediterranean basin, groundwater (GW) constitutes a crucial resource for socio-economic development. However, albeit its importance, it is presently undergoing a rapid deterioration. On the one hand, because the propagation of intensively irrigated agricultural areas has generated dramatic increases in water demand (Martínez-Santos and Martínez-Alfaro, 2010; Van Camp et al., 2010). On the other hand, the Mediterranean Region is being subject of water scarcity due to climate change (Iglesias et al., 2007). This situation is resulting in an increasing imbalance between the water that is withdrawn and the GW recharge, causing an impoverishment in GW quantity and quality (Voudouris et al., 2010; Pereira et al., 2009). Most of the policies implemented in the Mediterranean basin aim to improve the efficiency of GW use through innovative irrigation techniques or to restrict the GW use through tight control of farmers activities (Giordano et al., 2015). Nevertheless, evidence suggests that many times those policies largely failed to achieve a sustainable use of GW (Giordano et al., 2013; Portoghese et al., 2013). Several scholars have argued that these failures are mostly due to an over simplification, or in some cases even the neglect, of the uncertainty and complexity associated with the water management systems (Knűppe and Pahl-Wostl, 2011; Borowoski and Hare, 2007). Specifically, there is complexity due to the densely interconnected networks in which decision-actors operate, which span between and across ecological, economic and socio-political domains. There is also uncertainty because what other decision-actors involved in the network are going to do is largely unknown, making difficult to predict whether the choices pay off or not (Rosenhead and Mingers, 2001).

In these complex and uncertain environments, it is very difficult to determine how effective a policy will be. Part of the difficulty resides in the fact that even when a policy is targeted to regulate the behaviour of individual actors (e.g.

farmer's actions), actors interdependent in performing their tasks, so any action choice will influence and be influenced by the actions choices of the other actors (Brock and Durlauf 2001).

Action choices are not neutral, but commensurate with the perspectives and frames held by the actors making the decisions. The group decision frame explicitly incorporates each member's frame, so it is broader than any member's decision frame (Keeney, 2015). What is more, according to the Simon's "bounded rationality" theory, decision-makers behave under the influence of a local satisfaction criterion, meaning that they will choose the solution subjectively considered satisfactory (Simon, 1954, 1956, 1957). The problem is that when these frames do not overlap or are incompatible, they lead to a situation of ambiguity (Brugnach and Ingram, 2012).

Ambiguity refers to the degree of confusion that exists among actors in a group for attributing different meaning to a problem that is of concern to all (Weick 1995). In a management situation, it indicates that there are discrepancies in the way in which the situation is interpreted. It originates from differences in interests, values, beliefs, background, previous experiences and societal position among the actors (Van den Hoek et al., 2013). Under the presence of ambiguity it may not be clear if a situation is problematic or not, or if there is a problem what the problem is, or whose problem it is, or what actions path should be taken to deal with it (Brugnach et al., 2011; Brugnach and Ingram, 2012 for reviews and details)

In multi actors setting the presence of ambiguity may have diverse implications. On the one hand, a diversity in frames can offer opportunities for innovation and the development of creative solutions (Brugnach and Ingram, 2012). From this point of view, a certain degree of ambiguity is desirable to foster the collaborative work needed to manage GW resources. On the other hand, the presence of ambiguity can be a source of discrepancies or conflict in a group. When this happens, ambiguity can result in a polarization of viewpoints and the incapacity of a group to create a joint basis for communication and action, conditions that can greatly interfere with the development of collective actions (e.g., Brugnach et al. 2011). The extent to which the lack of shared meaning alters the implementation of a policy is largely dependent on the behavioural repertoires actors use to interact with one another (Donnellon et al. 1986). It has been suggested that divergent frames can still yield organized collective action when the interaction frames (i.e., communication behaviours actors use) are sufficiently aligned (Dewulf et al. 2009).

This work aims to demonstrate that sufficient overlap in interaction frames is a *sine-qua-non* condition allowing decision-actors with divergent problem frames to interactively co-construct overlap in their decisions; that is, to develop collective action. To this aim, ambiguity in interaction frames needs to be addressed.

In order to demonstrate this proposition, we refer to the *Interaction Space* (IS) as a way to formalize the decision-actors' interaction frames (Ostanello, 1990; Ostanello and Tsoukias, 1993). The IS is a collaborative space where a *meta-object* is identified as the articulation of the participants' problem representation. The concept of IS has been introduced to represent a formal meeting structure of decision-actors from different organizations that allows exchange and communication condition in a public confrontation. Formally, an IS is composed by a set of elements (participants A, objects O and resources R) and a structure of relations S on this set constitute an IS model.

$$IS = < A, O, R, S >$$

Intervening actors are the elements of the set A and the set of resources R represents the factors (quantifiable, non-quantifiable or behavioural) concerning the objects with which the participants are involved. The set of objects O is made by the elements for which the actors enter in the IS. The architecture of relations on these three sets can be represented by the following set:

$$S = \{S_o, S_{ao}, S_{aor}\}$$

More details and the multi-step procedure that enables the building of the IS is explained by Ostanello and Tsoukiàs (1993).

To test the research hypothesis, a methodology based on IS analysis and Causal Loop Diagrams (CLDs) was developed that allows us to explicit and consider the different interaction frames, as well as to analyse how these differences can result in feedback loops and delay mechanisms as sources of policy resistance. We apply this model to a study in the Apulia region (Southern Italy) to better understand the feedback mechanisms that are hampering the implementation of the regional GW protection plan.

2 Materials and methods

The methodology implemented in this work is based on the coupling between IS development, and system dynamic analysis through CLDs. The former allows us to analyse the ways different decision-actors perceive the interaction that needs to be established with other actors in order to achieve their goals related to GW management and protection. The CLDs is implemented to investigate how differences in IS perception influence the decision-actors' understanding of the system dynamics and the actions needed to keep the system in equilibrium. Finally, the different decision-actors' interaction spaces and problem frames are compared in order to address the ambiguity issues.

The following sections describe the different phases and the methods implemented.

2.1. The decision-actors' understanding of the interaction space

An interaction space has been defined as a formal or informal structure that is governed by a number of rules and aims at providing a field of interaction to a finite set of actors (Mazri et al., 2007; Daniell et al., 2010). IS provides a useful basis for understanding multi actors decision dynamics. Recently, the IS has been used more explicitly in the domain of public policy. It has been defined as an abstract legitimation space where the decision-actors reveal (at least partially) their concerns, preferences, values and goals, where they commit and look for resources and where they are able to seek for and create legitimation, namely agreement on decisions and actions, through relations and discussions (De Marchi et al., 2014).

Previous works demonstrate how the development of a shared IS requires a common understanding of the main elements forming the IS, i.e. participants, objects and resources. An analyst is called for supporting the process of creating the shared IS through the analysis of the interaction mechanisms between subjects involved in decision-making process, and the identification of all those elements related to the decision objects (Bouyssou et al., 2006; Mazri et al., 2007; Las Casas et al., 2012).

In this work, the methodology for IS development was implemented in order to analyze the main differences among decision-actors' individual perceptions of the IS. To this aim, individual semi-structured interviews were carried out involving the main stakeholders (Giordano et al., 2013). Participants were first required to specify the core of the problem from their viewpoint. Subsequently, they were asked to identify the causes of changes in the problem core and its main effects (as suggested by Vennix, 1996). The results of the interviews were used to define the taxonomy of actors, objects and resources, as defined by Ostanello and Tsoukias (1993).

The process for modelling the actors' understanding of the IS structure started by defining the relations $S_{ao} = \{(a, o)\}$ between the elements of the set of actors A and the set of their objectives O. S_{ao} is a binary attribution relation between agent and objective: i.e. actor a is interested in object o, or object o pertains to actor a.

Next step aimed at structuring the relationships between the actors and the resources used by them to promote their interests in the interaction with other participants in order to achieve their objectives. For each pair (a, o) it is possible to define the associative relationship $S_{aor} = \{(a, o)r\}$, representing the actor a activating the resource r in order to achieve the object o. The sets of relationships between actors, objectives and resources represent the formalization of the IS.

2.2 The decision-actors' understanding of the system dynamic

The second phase of the implemented methodology aims at spelling out the different frames that decision-actors hold regarding the GW management and the dynamic behaviour of the system. In this work, frames are represented as mental models. Among the different definitions of mental model available in the scientific literature (Schaffernicht, 2006), we assume that a mental model is built of causal knowledge about how a system works and evolve in time (Sterman, 1994). Following Schaffernicht and Groesser (2011), we refer to these models as Mental Model of Dynamic Systems (MMDS). According to this definition, a mental model is capable of representing the perceived cause-effect chains influencing the dynamic evolution of a system (Jones et al., 2011).

The results of the interviews were the structured in Causal Loop Diagram (CLD). CLD are tool for representing the feedback structure of systems being modelled (Simonovic, 2011). CLD were used in the developed methodology to capture the participants' dynamic hypotheses, elicit and structure the participants' mental models, and to communicate the feedbacks that, according to their understandings, were responsible for the problem. For a detailed description of CLD development process, a reader could refer to (Vennix, 1996). In this work, the actors' CLD were developed accounting for their understanding of the core of the problem, and the main causes and effects of its change.

The analysis carried out in this work aimed at demonstrating how differences in the perception of the interaction frames lead to different understanding of the dynamic evolution of the system and, thus, in different actions to keep the system in equilibrium. To this aim, an ambiguity analysis was carried out, as described in the following section.

2.3. Ambiguity analysis

In order to assess to which extent the ambiguity hampers the development of a collective action, this section analyses the differences among the decision-actors' perception of the IS and their understanding of the system dynamic.

Concerning the first point, the Jaccard index was used to calculate the distances among the different IS perceptions. That is, this index was used to measure the extent to which the different IS perceptions could be considered overlapping. The Jaccard index or Jaccard similarity coefficient was introduced by the botanist Paul Jaccard in 1901 in (Jaccard, 1901) as the ratio of the size of the intersection between two sets and the size of their union. The Jaccard index is now a classical and commonly used measure of similarity between sets in many applications since its introduction (Bouchard et al., 2013). Formally, let us consider two sets, A and B, each having n binary attributes, the coefficient measures the degree of overlap between two sets by computing the ratio of the number of shared attributes between A and B. The region of intersection $(A \cap B)$ and union $(A \cup B)$ between these two sets can be measured according to set theory. Thus, the Jaccard index is defined as follows:

$$J\ (A, B) = \frac{|A \cap B|}{|A \cup B|}$$

The Jaccard index was assessed by considering the actors' perception of the IS as the sets to be compared.

The total number of each combination of attributes for both A and B are shown below:

J_{11} denotes the total number of attributes where A and B both have a value of 1; J_{00} denotes the total number of attributes where A and B both have a value of 0; J_{01} denotes the total number of attributes where the attribute of A is 0 and the attribute of B is 1; J_{10} denotes the total number of attributes where the attribute of A is 1 and the attribute of B is 0

Each attribute of A and B can either be 0 or 1 and $J_{11} + J_{00} + J_{01} + J_{10} = n$

The Jaccard index is given as

$$J = \frac{J_{11}}{J_{11} + J_{01} + J_{10}}$$

It is defined in the range $[0,1]$, where 0 indicates that there is no similarity, 1 indicates congruence. Respectively, the Jaccard distance $D_J = 1 - J$.

In this work, the Jaccard index is used to assess to which extent the decision-actor's perception of the IS is far from the one developed by the analyst. It is used to measure the degree of IS complexity perceived by each decision-actors. We assumed that the analyst had a more complex understanding of the IS because she/he had access to a more complete knowledge about the problem core compared to the single participants. The lower the Jaccard index, the more limited is the actor's IS perception.

The ambiguity analysis was completed comparing the decision-actors' understanding of the system dynamic. For this reason, a pairwise comparison was implemented among the different decision-actors, considering their understanding of the problem core elements, the dynamic evolution of the system and the drivers influencing the system dynamic. To this aim, the MMDS comparison method described in Schaffernicht and Groesser (2011) was implemented. The method aims at assessing the degree of similarity between either models of different decision-actors – i.e. the between-subjects measure – or between different versions of a model of one subject before and after an intervention – i.e. within-subject approach. In our work, the between-subjects approach was implemented.

The method is based on three measures: i) Elements Distance Ratio (EDR), which expresses the differences between two MMDS considering the variables and the causal links in each pair of MMDS; ii) Loop Distance Ratio (LDR), which indicates the similarity between each pair of loops for the two compared MMDS; iii) the Model Distance Ratio (MDR) is the average of all loop distance ratios (Schaffernicht and Groesser, 2011).

The EDR was calculated by aggregating the similarity degree among variables and the similarity degree among links. For what concerns the variables, the similarity degree was calculated as ratio between the common variables and the total number of variables. The similarity among the causal links was assessed by considering the three main elements: i) the direction of the link; ii) the polarity; iii) the strength of the link. The analysis accounted for the indirect links as well. An indirect link means that two variables are connected through a third one.

The LDR was calculated comparing the loops with similar contests in two MMDS. The identification of the loops that can be compared required the intervention of the analyst (Schaffernicht and Groesser, 2011). The LDR accounted for the polarity and the variables within loop. The LDR between the loops m and n is, hence, calculated according to the following equation:

$$LDR(m,n) = lpold(m,n) + EDR(m,n)$$

In which $LDR(m,n)$ represented the loop distance between m and n; $lpold(m,n)$ is the difference in polarity between m and n; $EDR(m,n)$ is the element distance ratio as described previously.

Finally, the MDR allowed to define the distance between two actors' MMDS by aggregating the LDR for each pair of similar loops.

3 Case study description

The Apulia region is a peninsular territory covering about 20,000 km^2 in Southern Italy. It exhibits a typical example of groundwater overexploitation due to the limited availability of surface water resources. Over many centuries, gentle orographic features and high population density have led to the intensification of farming, accompanied by the replacement of existing natural vegetation with agricultural crops (more than 76% of the total area is used for agriculture). Starting from the 1960s, traditional rain-fed agriculture has been replaced by irrigated farming and water-intensive crops (irrigated crops now occupy about 17% of the region's agricultural land). Besides the development of some multipurpose artificial reservoirs (from the 1950s to the 1980s), the main drivers of irrigated farming have been innovations in pumping and irrigation technologies and the implementation of policies favouring irrigated agriculture. Specialized agriculture is a vital economic resource for Apulia, with cereals and vegetables mainly grown in the fertile central northern zone, and olive trees and vineyards dominating the central and southern areas of the region. Agricultural development in the region has been responsible for several interconnected environmental pressures involving water resources (water table depletion and seawater intrusion in GW), landscape management (extensive changes in land use, mono-cultures) and biodiversity (loss of soil fertility, replacement of natural species).

In the last decade, several activities aiming to increase knowledge about the state of the GW resources have been funded and implemented by the regional authority. These studies showed the serious effects of seawater intrusion and the consequent reduction of the GW quality. The seawater intrusion in the GW had negative impacts on both the environmental resources and on the socio-economic development of the rural areas. The quality and quantity of crop production along the costs decreased due to the limited availability of GW for irrigation. Nevertheless, the exploitation of GW in the central part of the regional territory did not decrease.

In order to protect the quality of GW, the regional water authority proposed the enforcement of restrictive measures in the use of groundwater. In agreement with the Water Framework Directive (CEE 2000/60) a Water Protection Plan was approved by the regional authority in 2009 in which a 20-40% reduction of GW pumping was set with respect to the current amount of used water. These measures were defined based only on technical knowledge, without considering the potential impacts on the different stakeholders. Although stakeholders' involvement is explicitly required by the WFD, in this case it was implemented only at the end of the whole process and was aiming to provide stakeholders with information concerning decisions already taken.

The new legislation caused strong conflicts between farmers, the regional authority and the irrigation consortium due to the expected economic damages to the agricultural sector which is highly dependent on irrigation practices. Due to this conflicting situation, the Water Protection Plan has not been implemented yet, and the regional authority is carrying out a time consuming revision process.

4. Results

The described methodology was implemented to support the identification and analysis of the policy resistance mechanisms hampering the implementation of the regional policy for GW protection. To this aim, individual semi-structured interviews have been carried out involving the main decision-actors involved in GW management and protection, i.e. the regional authority, the irrigation consortium (that is, the organization responsible for the management of the public irrigation system), and the farmers. The interviews were aiming at eliciting their understanding of GW management in drought conditions, and of the role played by the other decision-actors. Finally, the decision-actors' problem frames were used to analyse the ambiguity and to draw some conclusions about how ambiguity affected the collective decision-making process. The following sections describe the different phases of the methodology.

4.1. Individual perception of the interaction space

Considering the case study policy-making environment described in Giordano et al. (2014), the elements forming the IS can be formalized by the analyst as following:

Actor			**Type**
a_1	I	Irrigation consortium	Organization
a_2	F	Farmers	Individual
a_3	Reg	Regional authority	Organization

Table 1. The actors set A

Objects	
o_1	Environmental protection
o_2	Agricultural productivity
o_3	Effectiveness of the irrigation water management
o_4	Water availability
o_5	Decrease of groundwater overexploitation
o_6	Water distribution and control of the irrigation network
o_7	Reduction of water consumption during drought

Table 2. The objects set O

Resources		**Type**
r_1	Economic resources	Quantifiable
r_2	Legislative constraints and regulations	Quantifiable
r_3	Information flow	Not quantifiable
r_4	Decisional power	Behavioural
r_5	Water accessibility	Quantifiable
r_6	Illegal actions	Behavioural
r_7	Technical resources	Quantifiable
r_8	Yield	Quantifiable

r_9	Control of the territory	Not quantifiable

Table 3. The resources set R

The analyst's view of the IS could be structured as in table 4:

Objects		**Actors**		**Resources**	
o_1	Environmental protection	a_3	Regional Authority	r_2	Legislative constraints and regulations
o_2	Agricultural productivity	a_1	Irrigation consortium	r_1	Economic resources (water price)
				r_3	Information flow
		a_2	Farmers	r_5	Water accessibility
				r_6	Illegal actions
				r_8	Yield
o_3	Effectiveness of the irrigation water management	a_1	Irrigation consortium	r_1	Economic resources (water price)
				r_3	Information flow
		a_3	Regional Authority	r_2	Legislative constraints and regulations
o_4	Water availability	a_1	Irrigation consortium	r_3	Information flow
		a_2	Farmers	r_3	Information flow
				r_6	Illegal actions
				r_8	Yield
		a_3	Regional Authority	r_2	Legislative constraints and regulations
o_5	Decrease of groundwater overexploitation	a_3	Regional Authority	r_2	Legislative constraints and regulations
		a_1	Irrigation consortium	r_1	Economic resources (water price)
				r_7	Technical resources
o_6	Water distribution and control of the irrigation network	a_1	Irrigation consortium	r_1	Economic resources (water price)
				r_2	Legislative constraints and regulations
				r_3	Information flow
				r_4	Decisional power
				r_7	Technical resources
		a_2	Farmers	r_7	Technical resources
				r_6	Illegal actions
o_7	Reduction of water consumption during drought	a_1	Irrigation consortium	r_4	Decisional power
				r_7	Technical resources
o_8	Env., econ. and social sustainability of the agricultural activities	a_3	Regional Authority	r_2	Legislative constraints
				r_9	Control of the territory

Table 4. The analyst's understanding of the IS according to the relations S_{oar}

The results of the individual interviews were used to structure the decision-actors' understanding of the IS.

The regional authority

The regional authority (*Reg*) perceives the role of farmers as crucial, whereas ignore the impacts of irrigation consortium's actions on the GW management. This decision-actor is responsible only for the management of the irrigation network. Moreover, the regional authority's perception of farmers' resources is limited to water accessibility for irrigation and the economic resources (yield) to adapt the crop plan. The main farmers' objective according to the regional authority view is the increase of agricultural productivity. Table 5 describes the IS model of the regional authority $< A, O, R, S >_{Reg}$.

$< A, O, R, S >_{Reg}$			
$(A)_{Reg,1}$	Perception of other actors	a_2	Farmers
$(O)_{Reg,1}$	Perception of other actors' objectives	o_2	Agricultural productivity
$(R)_{Reg,1}$	Perception of other actors' resources	r_5	Water accessibility
		r_8	Yield
$(A)_{Reg,2}$	Perception of other actors	a_1	Irrigation consortium
$(O)_{Reg,2}$	Perception of other actors' objectives	o_6	Water distribution and control of the irrigation network
$(R)_{Reg,2}$	Perception of other actors' resources	r_7	Technical resources

Table 5. The regional authority's understanding of the IS

The Irrigation consortium

The irrigation consortium's view (*I*) of the IS $< A, O, R, S >_I$ is characterized by a limited understanding of the farmers' objectives and resources (table 6). According to its perception of the IS, farmers aim at improving agricultural productivity and to keep positive the irrigation balance. In order to achieve this goal, farmers could use their economic resources to change their cropping plan. The irrigation consortium perceives the regional authority as the actor interested in protecting the environmental resources through legislative constraints and regulations.

$< A, O, R, S >_I$			
$(A)_{I,1}$	Perception of other actors	a_2	Farmers
$(O)_{I,1}$	Perception of other actors' objectives	o_2	Agricultural productivity
		o_4	Water availability
$(R)_{I,1}$	Perception of other actors' resources	r_3	Information flow
		r_8	Yield
$(A)_{I,2}$	Perception of other actors	a_3	Regional Authority
$(O)_{I,2}$	Perception of other actors' objectives	o_1	Environmental protection
$(R)_{I,2}$	Perception of other actors' resources	r_2	Legislative constraints and regulations

Table 6. The irrigation consortium's understanding of the IS

The farmers

In order to develop the farmers' understanding, interviews were carried out with a sample of farmers. The selection of the sample and the method implemented to aggregate their inputs are described in (Giordano et al., 2013). Farmers (*F*) perceive the constraints imposed to their decision-making process by the actions taken by the regional authority and irrigation consortium. Specifically, farmers consider the regional authority as the entity imposing limits to the GW use for irrigation purposes through legislative constraints. Moreover, they consider the irrigation consortium as responsible for controlling the distribution of the irrigation water and for reducing the water consumption in case if drought. Legislative, economic and technical resources are used to this aim. The farmers' perception of the IS model $< A, O, R, S >_F$ is explained in the table 7.

$< A, O, R, S >_F$

$(A)_{F,1}$	Perception of other actors	a_1	Irrigation consortium
$(O)_{F,1}$	Perception of other actors' objectives	o_6	Water distribution and control of the irrigation network
		o_7	Reduction of water consumption during drought
$(R)_{F,1}$	Perception of other actors' resources	r_1	Economic resources (water price)
		r_2	Legislative constraints and regulations
		r_4	Decisional power
		r_7	Technical resources
$(A)_{F,2}$	Perception of other actors	a_3	Regional Authority
$(R)_{F,2}$	Perception of other actors' objectives	o_5	Decrease of groundwater overexploitation
$(R)_{F,2}$	Perception of other actors' resources	r_2	Legislative constraints and regulations

Table 7. The farmers' understanding of the IS

4.2. The Mental Models of Dynamic System

The regional authority

The main issue to be addressed was the excessive exploitation of GW for irrigation purposes. According to the regional authority's understanding of the system dynamic, the main driver influencing the increase of GW exploitation was the uncontrolled increase of the water demand due to the increase of irrigated areas, caused by the tendency of farmers to prefer irrigated crops. The causes of the GW exploitation are perceived by the regional authority as forming a reinforcing loop (R1 in figure 1), which provokes an exponential increase of GW exploitation, pushing the system towards an unsustainable use of GW.

As consequence, the GW level and the GW quality decrease below the desired level. The regional authority uses the GW monitoring system to control the state of the resource. Whenever the GW quality is lower than desired, a pressure to implement a GW protection policy would become crucial in order to enhance GW quality. In the regional authority's problem understanding, the balancing loop (B1) could be activated by imposing limits to GW use for irrigation purposes through the GW protection policy. The lower the GW quality, the greater the pressure and the tighter the limits.

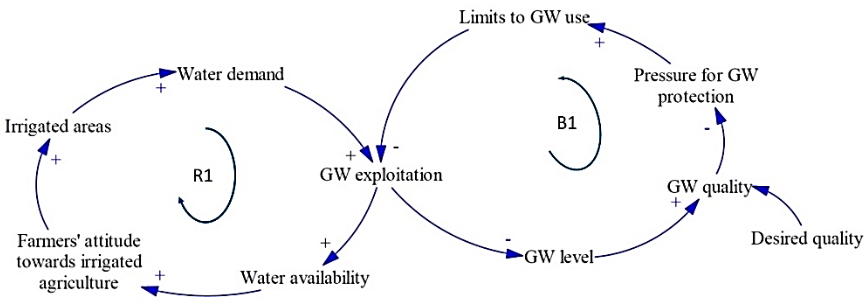

Fig. 1. CLD representing the regional authority's problem frame

From the dynamic point of view, the regional authority problem understanding can be conceptualized as a "limit-to-growth" archetype (Vennix, 1996). That is, the GW exploitation quickly accelerates due to the reinforcing loop, until it reaches the regional authority desired level. At this point, the strength of the GW policy implementation will provoke a shift in dominance between the two loops, making the balancing loop stronger than the reinforcing loop.

The irrigation management consortium

The main issue that has to be dealt with is to guarantee the equal distribution of the water for the whole duration of the irrigation season. Otherwise, the water provision to farmers would last for a shorter period, causing irreversible damages to the crops and, thus, provoking strong conflict between farmers and irrigation manager. The duration of the irrigation season is assessed by comparing the water volume stored in the reservoir and the expected water demand by farmers.

According to the irrigation consortium's problem understanding, the main drivers influencing the system dynamic is the increase of water demand for irrigation, which is caused by the increasing farmers' attitudes towards the irrigated agriculture. The water availability would lead farmers to increase the irrigated areas and, thus, push the water demand toward an unsustainable level (reinforcing loop R2). In order to re-establish the system equilibrium avoiding the exponential growth of water consumption, the irrigation consortium would implement a water conservation policy aiming to force farmers to reduce the amount of water used for irrigation purposes. This strategy is mainly based on increasing the water price. In the irrigation consortium problem understanding, this strategy would force farmers to reduce the irrigated areas and/or to select less water demanding crops (figure 2).

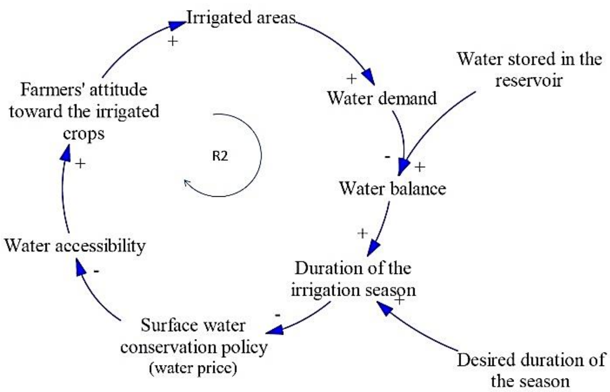

Fig. 2. CLD representing the irrigation consortium's problem frame.

Farmers

The farmers' mental model is shown in figure 3.

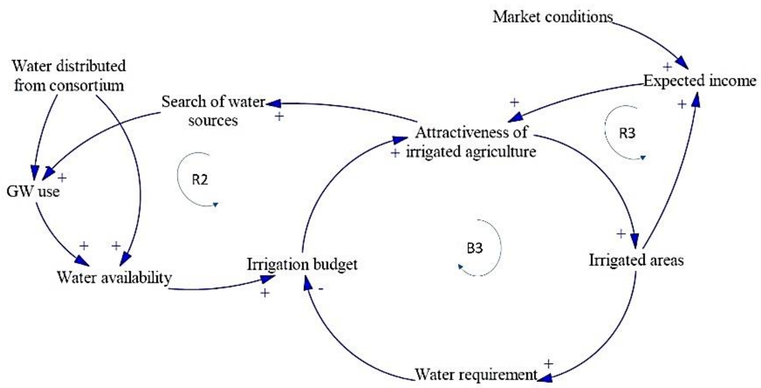

Fig. 3. CLD representing the farmers' problem frame

The problem core was the irrigation budget. That is, farmers perceived the balance between water requirement and water availability for irrigation as a crucial element. Farmers perceive the irrigation consortium's decision as a fundamental barrier hampering the full satisfaction of the water demand.

The farmers' mental model seems to be dominated mainly by a balancing loop connecting the attractiveness of irrigated agriculture to the water availability. That is, in normal conditions, the farmers would increase the irrigated areas up to a certain limit, which is represented by the water availability. Nevertheless, the variable "market condition", which is considered as an external driver by farmers, could prevent the system to achieve the equilibrium. This variable influences the farmers' expectation about their income. That is, in case of high market price for the irrigated products, the farmers would perceive the irrigated agriculture as extremely attractive. Farmers perceive market conditions as more influential than the water availability. The reinforcing loop activated by the market conditions pushes farmers to overcome the limits imposed by the irrigation budget in order to increase the expected income. To this aim, farmers try to increase the amount of water available for irrigation, by searching for alternative water sources. Considering the lack of treated water re-use policies in the study area (Giordano et al., 2007), farmers increase the water availability for irrigation by increasing the GW exploitation, although this behaviour is against the regional law (illegal pumping). This is mainly because farmers' perception of the IS does not consider the control of the territory as a regional authority's resources. That is, farmers perceive GW as an easily accessible resource. This perception could change in case of strong drought phenomena, when the energy costs for GW withdraw increase due to the drop of the water level. In the area closed to the coast, farmers are also concerned about the GW quality due to seawater intrusion. This issue was not considered in this work because mainly farmers from the central part of the Apulia region were involved.

4.3. Ambiguity analysis: the Jaccard Index

Let us consider the sets $< A, O, R, S >_{An}$ being entirely the IS model from the vision of the analyst, and the partial sets $< A, O, R, S >_{I}, < A, O, R, S >_{F}, < A, O, R, S >_{Reg}$ for each decision-actor. The following table shows the Jaccard index for each actor:

Analyst	Actor	J index	Distance
Analyst	Irrigation consortium	0,42	0,58
Analyst	Farmer	0,48	0,52
Analyst	Regional Authority	0,35	0,65

Table 8. Jaccard index and the distance between the actors' perception of the IS and the analyst's view

The low level of J index demonstrates the limited capability of each decision-actors to fully comprehend the complexity of the IS related to GW management and protection. Interestingly, the irrigation consortium and the regional authority, that is, the two most influential decision makers, are characterized by the lower Jaccard index. This is mainly due to their assumptions about the farmers' behaviour without checking their actual actions.

4.4. Ambiguity analysis: the Models Distance Ratio

The MDR is based on a pairwise comparison among the individuals CLD representing the actors' MMDS. In order to make the CLD comparable, a preliminary operation was needed in order to guarantee that the same names were used for similar variables. To this aim, some changes were made - e.g. “farmers’ attitude toward irrigated crops” became “attractiveness of irrigated agriculture”. The EDR accounts for differences in the set of variables and in the causal links, both direct and indirect. Implementing the formula suggested by Schaffernicht and Groesser (2011), the following distance matrix was obtained (table 9). As expected, the highest distance is between regional authority and farmers.

	Regional authority	**Irrigation Consortium**	**Farmers**
Regional authority	-	0,32	0,87
Irrigation Consortium	0,32	-	0,76
Farmers	0,87	0,76	-

Table 9: EDR for each pair of decision-actors.

In order to calculate the LDR, a comparison among the feedback loops in the MMDS was carried out. Table 10 shows the list of all loops in the decision-actors’ MMDS.

Loop	MMDS	Polarity	Variables
R1	Regional Authority	+	Water demand Irrigated areas Attractiveness of irrigated agriculture Water availability GW exploitation
B1	Regional Authority	-	Limits to use GW Press. for GW protection GW quality GW level GW exploitation
B2	Irrigation Consortium	-	Irrigated areas Attractiveness of irrigated agriculture Water availability Water conservation policy Duration of the irrigation season Water balance Water demand
R2	Farmers	+	Attractiveness of irrigated agriculture GW exploitation Water availability Irrigation budget Search of water source
R3	Farmers	+	Attractiveness of irrigated agriculture Irrigated areas Expected income market condition
B3	Farmers	-	Attractiveness of irrigated agriculture Irrigated areas Water demand Irrigation budget

Table 10: List of feedback loops in the MMDS.

In order to calculate the LDR, the analyst should identify and compare pairs of loops that correspond to each other in terms of their contents. Context similarity could concern R1-R2 and B1-B2. The LDR between two loops was calculated accounting for the differences in polarity and the numbers of variables. Finally, the MDR between two actors was calculated combining the

EDR, and the LDR of all the common loops between them. Table 13 shows the MDR for the actors involved in this work.

	Regional authority	**Irrigation Consortium**	**Farmers**
Regional authority	-	0,21	0,90
Irrigation Consortium	0,21	-	0,82
Farmers	0,90	0,82	-

Table 11: MDR between the actors involved in GW management

As expected, the maximum MDR was between regional authority and farmers. This was because the way they perceived the GW strongly influenced their understanding of the system dynamic. The regional authority perceived the GW as a limited resources whose overuse needed to be balanced. Whereas farmers perceived the GW as a freely accessible source of water that could be used to satisfy the water demand when the irrigation consortium reduce water availability due to drought conditions.

5. Discussion

5.1. Interpreting ambiguity in relation to IS and MMDS

The method described in the previous section allows us to demonstrate that ambiguity in problem framing is composed by two main elements: i) ambiguity related to the interaction frames; ii) ambiguity related to the problem understanding. In this section, we demonstrate how these two classes of ambiguity are strongly interrelated.

Through the comparison between each actor's perception of the IS and the integrated view (the analyst's), the Jaccard index analysis allows the identification of the main drawbacks in the actors' perceptions, that is, the missing elements in the partial IS perceptions. The Jaccard index assessment shows that the irrigation consortium neglects the capability of the farmers to activate illegal pumping (resource in the IS structure) to achieve their main goal, that is, to increase agricultural productivity. This leads the irrigation consortium to consider the water price policy as the most suitable action to re-establish the system equilibrium. Moreover, the irrigation consortium considers the information flow as a crucial resource in the interaction with farmers. According to the irrigation consortium's problem understanding, the information provided to farmers about the availability of water and the water price leads them to change their cropping plans, in order to reduce the amount of water required. On the other side, farmers do not consider the information flow as a resource, because it is not considered timely. Therefore, the two actions implemented by the irrigation consortium to keep the water consumption at a sustainable level are actually ineffective. Nevertheless, due to its limited understanding of the IS complexity, the irrigation consortium is not fully aware of the failure of its decision-making process. Therefore, this decision-actor is not willing to change the way it interacts with the others.

Similarly, the Jaccard index comparison between the regional authority's IS perception and the integrated IS highlights the main limits hampering the implementation of the GW protection policy. Firstly, the regional authority ignores the role played by the market (resource: yield) in influencing the farmers' decisions about the irrigated areas, as shown in farmers' MMDS. The regional authority decision-making process is strongly influenced by the assumption according to which the water availability is the only resource influencing the farmers’ attitude towards the irrigated agriculture. Moreover, the regional authority perceives the control of the territory as a crucial resource to achieve its main goal, that is, the protection of the GW. However, farmers do not perceive this control and, consequently, do not consider the regional authority capable of imposing limits on GW exploitation through legislation constraints and regulations. The farmers’ MMDS does not contain variables concerning the GW limits. Even in this case, the regional authority is implementing an ineffective policy. Due to its limited understanding of the interaction with farmers, it does not have the means to became aware of its failures. In this condition, this decision-actor is not willing to change its own decision.

5.2. Dialogue with decision-actors in order to increase the mutual problem understanding

We can infer that the lack of alignment among the interaction frames, measured as distance among the interaction space perceptions, hampers the creation of common ground to support the development of collective action. The limited understanding of the IS complexity leaded decision-actors to make simplifying assumptions about the other actors’ behaviour in the IS, and to take decisions based on these assumptions, as shown in the actors’ MMDS. In order to overcome this barrier, a crucial step was to create a sufficient overlap among the decision-actors’ interactions frames by reducing the distance among the IS perceptions. To this aim, the results of the Jaccard index analysis were used in this work to initiate the debate among the decision-actors. Meetings with each of the decision-actors were organized in order to discuss the results of the analysis. The aim was to enhance their awareness concerning the actual shape of the IS. The elements missing from their IS perception were discussed. At the end of this phase, the involved decision-actors partly adapted their understanding, introducing new objectives and resources in their IS perception. Particularly, the irrigation consortium became aware of the importance of providing information to farmers in time to actually influence their decision process. It also became aware of the illegal pumping activities, which requires a better understanding of the impact of the water price policy. Finally, the regional authority introduced the irrigation consortium’s role in influencing the farmers’ behaviour. The Jaccard index after this round of meetings is shown in the following table:

Analyst	Actor	J coefficients
Analyst	Irrigation consortium	0,64
Analyst	Farmer	0,53
Analyst	Regional Authority	0,62

Table 12: Jaccard index after the second round of meetings with the decision-actors.

The table shows an increasing overlap among the interaction spaces, which allowed to overcome the differences among the decision-actors’ MMDS and to develop an integrated system dynamic model (figure 4).

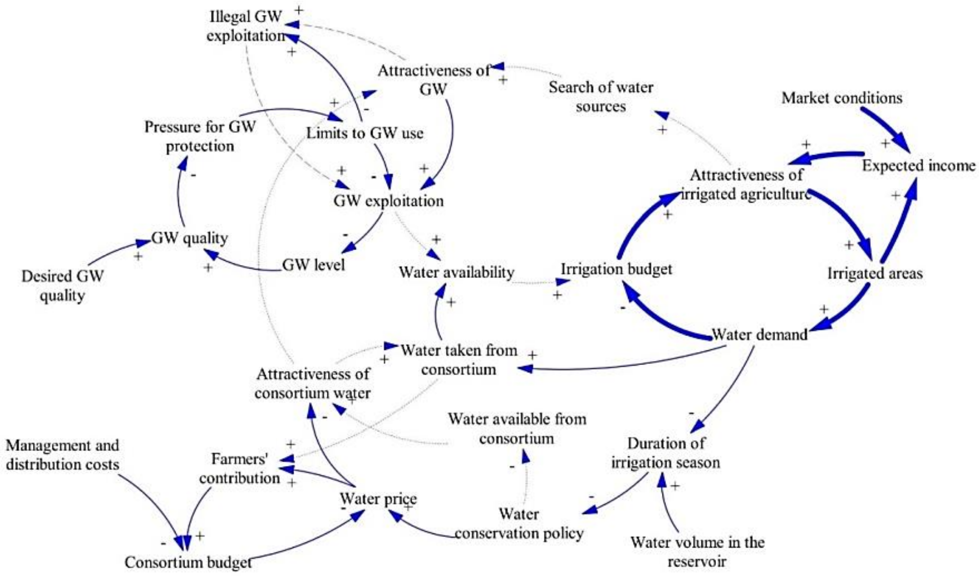

Fig. 4: Integrated CLD and feedback loops provoking policy resistance.

The model was developed by integrating the individual CLD and introducing the elements that allow the alignment of the ISs. The needed elements were identified through the Jaccard index analysis. Three main feedback loops seem to influence the system dynamic, i.e., the "market loop" influencing the farmers' behaviour, the "water conservation policy" loop influencing the interaction between irrigation consortium and farmers, and the "illegal GW pumping" loop influencing the interaction between farmers and regional authority. The "market loop" forces farmers to increase the irrigated areas and, thus, to increase the water consumption. The "water conservation" loop leads the irrigation consortium to increase the water price in order to compensate the reduction of the farmers' contribution (due to the shift toward the GW as source of water for irrigation) and to fully recover the management and distribution costs. The "illegal GW pumping" provokes an ever increasing change of the GW attractiveness for irrigation purposes.

The combined effects of these feedback loops hampered the implementation of the GW protection policy, since they lead the system towards an ever-increasing consumption of GW for irrigation purposes. Therefore, actions are required to de-activate these feedback loops. The debate among the decision-actors aiming at developing these actions is still in its early stages, but the integrated CLD, obtained through the alignment of the interaction frames, already demonstrates its capability to facilitate the creation of a suitable environment for collective action.

6. Conclusions

The experiences carried out in the Apulia case study support our initial research hypothesis. That is, ambiguity in problem framing represents a barrier to the development of collective action when it is not possible to develop a sufficient overlap among the decision-actors' interaction frames. Handling ambiguity does not require finding a compromise among the different problem frames. It rather implies a co-creative process aiming to generate new shared knowledge through the active involvement of different parties. This shared knowledge is at the basis of the collective actions. Our analysis demonstrated how this co-creative process could be hampered by the predominance of content-based knowledge over the relational-based knowledge, where the latter refers to the knowledge generated through the relations established among the different decision-actors (Brugnach and Ingram, 2013). By making explicit the problem and interaction frames this analysis can support processes of reframing and social learning (Pahl-Wostl et al. 2011).

This work demonstrates that collaborative knowledge production process claims for a decision-making environment in which the parties are fully aware of their role and the roles of the others in the interaction environment. The combined implementation of IS analysis and system dynamic analysis proves to be capable of improving the decision-actors' awareness of the main elements hampering the overlap among the decision-actors' IS perceptions and their impacts on the action effectiveness. The described methodology facilitates the development of a sufficient alignment among the interaction frames and, in doing so, creates more common ground to support the development of the collective actions.

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