Environmental, Social and Normative Networks in the MAELIA Platform

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Abstract. The MAELIA project consists in modeling the socio-environmental impacts of norms designing the management and governance of renewable natural resources and of the environment. In this paper we present the MAELIA project and in particular its network-like structures: several sub-systems of different nature (environmental, social, normative sub-systems) emerge and interact in a complex manner. This network point of view on the MAELIA platform will allow to use and to develop tools relying on graph theory and network analysis in order to understand the structures of these different interacting complex systems, to construct a platform taking into consideration these interactions and to build various scenarios for the analysis of the social and environmental coupled system sustainability.

Keywords: environmental norms, water management, resources, multi-agent system, impact assessment, social network, institutional networks, graph theory, simulation.

1 Introduction

The water is a resource for many different uses. The withdrawal of water volumes from resource pools and the possible change in the water geochemistry and quality induced by some uses might change the resource availability for other uses. Consequently uses of water in a given ecological or environmental context are competing. They are also often interdependent, sometimes in a non trivial way. For example, water can be stocked in dams and used for the hydroelectric production. This water is not immediately available for irrigation in the downstream areas. But irrigation is generally using some electric devices for extracting water from the groundwater or surface water reservoirs. At the basin scale, the consumption of electric power for irrigation can significantly rely on the energy power plants, and in particular on dams. In this case the hydroelectric production and irrigation are not only competing uses but they are also interdependent, asking for some arbitration in the priority affected to the different uses (these priorities are usually changing with the environmental seasonality and inter-annual variability).

The *agents* (a very abstract notion as will be seen here below) responsible for the uses, the exploitation or the valorization of the water resources, are somewhat indirectly interacting through the conjugated impacts of their (interdependent) actions on the resource. They also directly interact through cooperation or competition mechanisms (among others). These mechanisms in turn can be non-formal or formally institutionalized. Many different norms exist that tend to regulate these direct and indirect interactions, being socially *bottom-up* emergent, or – at least tentatively – enforced by some legal authority. More specifically, legal norms can have many different types and expected mode of affecting the agents' actions in order to obtain some targeted results (e.g. water quality, or water availability for all in case of resource shortage, etc.). In particular we find all the classical categories that deontic logic intends to analyze and to formalize (e.g. [1]) and a large spectrum of softer instruments like incentive policy or directives, etc., proposing general guidelines to be implemented at different organizational levels of the society.

However when designing or implementing new normative frames, or when norms are self-emerging, the question is raised on the expectations that can be formulated about their capacity to effectively regulate the coupled dynamics of the resource and ecological systems with the social systems. In this paper we briefly show in the context of the basin-scale water resource management, how the effectiveness and efficiency issues associated to the normative frames are intimately related to the underlying network structure of the ruled system. We also expose a few concepts (and tools) developed in Graph Theory that we plan to use in order to bring some understanding on the structural complexity of these socio-environmental systems and on their normative regulation.

2 The MAELIA Project

2.1 The Context of the Basin-Scale Water Management

Planetary environmental changes are affecting the water resources at the scale of river basins. Ecosystem dynamics is modified. The uses, access and perceptions of the resources are changing. But also new institutions are adapted or crafted in order to regulate the social versus ecological interactions for a sustainable development, creating the conditions for legitimate collective actions [2]. Many studies strongly suggest that the way these political, economical and social institutions (organizations, legal and social rules, incentives, etc.) are functioning is a key issue for the long term evolution of socio-environmental systems [3], pushing them to overuse and decline, or maintaining the fragile dynamical equilibrium between development and sustainability. At the same time it is now understood that no universal solution exists for reaching such balance in different context [4], [5], and that – like biodiversity – institutional diversity might be a key patrimony to be preserved too [6].

The systems of water resource management at the basin scale, as developed since decades in France [7] and now in Europe, tends to be a worldwide spread model. This approach is contrasting with strategies of sectorial and/or local water resource management. Whatever the chosen policy, the actors in charge of the management of this resource are asked to take decision or to help designing policy orientation faced to intricate problems with nearly no scientific tools supporting the evaluation of the evolving situations in a globally to locally changing context. In the MAELIA Project we start building some scientific integrative simulation tool for supporting policy-making and decision-taking for the water management.

2.2 The Objective of the Project and Main Issues

The MAELIA Project[1] (started in 2009) consists in developing a multi-agent system for the assessment of the impacts of the environmental norms, with some strong focus on issues related to the basin-scale water resource management. By environmental norms, we mean all the norms that are susceptible of having some environmental dimension or target. The impacts are sought on the water resource (quality and quantity), on the social practices related to the resource uses, exploitation and valorization, on the functioning and structures of the institutions and organizations directly or indirectly related to water management issues, or to the related production sectors (individual or industrial). The design and building of the platform is done in three main (parallel) steps: a) we perform an interdisciplinary analysis of basin-scale water management systems as observed in different environmental and political / national contexts; b) from these analyses we abstract some generic scheme summarizing a stylized view of how the environmental and social co-evolving systems are functioning, with some special attention given to the regulation brought by the normative embedding system; c) a generic platform structure and implementation is developed that is mirroring the schemes obtained in the previous step, and that allows interoperability between the multi-agent layers, the layers of some geographic information system gathering information on a given river basin, and some classical partial differential model(s) describing the physical and bio-geochemical dynamics of the water, soils and biological (from phyto-plankton to vegetation and higher levels of the trophic web) interacting compartments.

Equipped with the simulation platform we shall consider three central questions: 1) what are the impacts of a given normative system in different socio-economical and environmental contexts? 2) What are the impacts of different normative systems in a given socio-economical and environmental context? 3) Are these impacts consistent with the expectations of the legislating authorities or participating social groups? The first two questions require that on one hand the formal representation of the functioning of the environmental plus social coupled systems, and on the other

[1] In its initial stage, the MAELIA Project is involving four main groups: the LMTG, several teams for the *Maison des Sciences Humaines et Sociales* from the University of Toulouse 2 – among which a team of the Institute of Mathematics of Toulouse, the Research Institute of Computer Sciences of Toulouse IRIT, and a laboratory of the National Institute of Agronomy INRA/AGIR. See http://www.iaai-maelia.eu

hand the representation of the normative system, can be easily plugged and unplugged in the platform. Moreover several representations of socio-environmental coupled systems and of normative systems must be prepared in order to contrast their respective effects or reactions to the rest of the whole integrative system (including among others, external large scale environmental forcing or economical forcing, the agent and action layers, etc.). The third question is related to the choice of some explicit criteria allowing to test the validity of the functioning and design of the integrative platform and the simulations that will be performed. This issue is far to be trivial for two reasons: 1) we are going to assess the impacts of norms that point towards "*what should be*" and not towards "*what is*"; 2) we shall build scenarios of evolution of complex systems, projecting their trajectory in the future. On both aspects we generally have no direct data, observations or even narrative description that would allow applying the usual criteria of modern science for testing the validity of the model. Comparing the platform outputs with some external and independent expectation is a possibility that we are exploring.

3 A System of Complex Sub-systems

The approach chosen for building the integrative platform is based on cognition in the sense that we clarify and formalize the partial building blocks of knowledge provided by the different scientific disciplines and then build the schemes for their coordinated and integrative functioning[2]. One possible way to present the integrative platform is to present it as a network of several complex sub-systems, each sub-system presenting an underlying network-like structure. The corresponding mathematical object is a graph, say basically the pair constituted by a set of vertices and a set of edges linking some of the vertices two by two. We now briefly illustrate the network structures of the resource, social, action and norm sub-systems.

3.1 A Sub-system of Resources

The conceptual representation of several kinds of ecological systems or sub-systems is often relying on networks: box models for the water bio-geochemistry, trophic webs, population dynamics, elements energy and matter cycles, etc. [8], [9]. In the MAELIA Project we are interested in ecological dynamics because it is producing resources or services. The physical and geochemical dynamics of water is ruled by hydrological processes and interactions (atmosphere, rainfall, soils, rocks, etc.) but also by interactions with other components of the biosphere (bacteria, phyto- and zoo-plankton, vegetation, etc.) [10]. In these models, the vertices are not directly resources, but physical, chemical or biological variables (biomass density, population density and cohort spectra, etc.) which values represent the instantaneous state[3] of the water resources and of the other resources (soil, usable vegetation, livestock, etc.).

[2] At this level of description, these expressions should be taken in a very loose interpretation.
[3] In distributed system, these variables are also depending on some spatial independent variables (geographical coordinates, altitude or depth, etc.).

The edge between two vertices represents a functional link often itself formed of the superimposition of different processes with their own space-time dynamics. All these models are generally developed in the form of (stochastic) ordinary or partial differential equations non linear coupled systems, or in the form of agent-based models. They exhibit a rich spectrum of dynamical regimes that are mostly analyzed and characterized in the Dynamical System Theory [11], [12].

3.2 System of Social and Organizational Agents

The physical, biological and ecological entities just mentioned are resources only once some agents are using, exploiting or valorizing them. Basically the agents are themselves entities able to a) have various perceptions of their environment (including on the time varying and distributed states of the resources); b) undertake and realize actions; c) make decision, with regard to the actions they undertake, their possible coordination with the other agents, the communication and information exchange they perform with the others. We broadly distinguish two large classes of agents: institutional agents that have the responsibility of managing the resources (or ensuring the conditions for such management: for example Water Agencies, Regional Councils, etc.) and non institutional agents that mainly use, exploit or valorize the resources and ecological services: for example farmers (using water for irrigation, developing livestock farming, forestry, etc.), rural or urban inhabitants but also firms from the public or private sectors, associations, etc.

The analysis of the water resource management is central in our modeling for identifying these agents (e.g. [13]). The analysis of water governance also gives a view of the links existing between all these agents [14], [15]. We are building a typology of these links. Indeed different kinds of relationships exist between agents: inter-institutional links are often formalized (possibly as a legal norm); institutions might interact with non institutional agents in the form of incentives, or in creating the conditions for participatory forums to be held, enforcement of (legally legitimated) decisions, etc. The mode of interaction will be also different between individuals, and between a "collective" agent (for ex a firm, an NGO, etc.) and individuals. Of course not all possible links are represented in the platform. For example if in some context the familial links have no role in the use or management of the resources, they will not be represented. With this example we also see that modeling decisions have to be taken also in the sense of discarding some components of the real systems[4]. In summary in this sub-system, vertices are agents and edges links between them.

3.3 A Sub-system of Actions

Every agent has the capacity to perform different actions on the resources. This set of actions can be shared by all the agents of the same social group. The platform comporting different groups or types of agents, there will be several, non-necessarily

[4] Note that the capacities of perception, decision-making, strategic evaluation, as well as many attributes are encapsulated in the agents themselves.

disjoint, sets of actions. In this sub-system, the vertices of the underlying structure are elementary actions. Several such actions can be composed in order to form more complex actions, or series of actions. Such composition is represented as a path linking several consecutive elementary actions in a sequence. Not all actions can be composed together or in an arbitrary order. In other words not all links (and paths) are possible in the graph of actions.

Dependencies between actions are of two types. The first one is given by the conditionality of an action: the action a_i can be performed by agent A_j if and only if action a_k has been previously realized (possibly by another agent A_l). The link is representing the conditional dependence of the action a_i on the action a_k. Of course such conditionality can be set on several actions, the conditioned action being the source for several edges oriented towards the conditioning actions. The second kind of link concerns the consequence of an action, performing an action involves another action; that yields a directed network of actions.

The existence of a link between actions may be dependant of the intensity of the actions. For instance pumping water may involves, if this pumping exceeds a given threshold, the action of opening the floodgates of a dam. This is surely important in the design of the platform: a link that represents the fact that a given action has some impact on the course, magnitude or effect of another action. If an action magnitude or spec-time extension is parameterized, the effect of another action can be obtained by changing the scalar values of the parameters. However the main difficulty is probably not here. It is in the possibility to design modular actions, and to be able to compose them in a coherent way. Such objective requires the ongoing development of a meta-theory of action [16].

3.4 A Sub-systems of Norms

In the MAELIA project we distinguish two large classes of norms: social norms and legal norms. The first kind of norms is embedded in the social tissue and is more or less regulating the interweaving of agent interactions. These norms might be non-explicit though known or shared by most of the agents. As for actions, social norms can present some conditionality interdependency or (mutual) impacts or effects, one norm changing or modulating the way another norm will regulate the behavior and actions that are under their own domain. The class of legal norms, their types, modes of implementation, efficiency and effectiveness are receiving much attention from lawyers, sociologist, political sciences, etc. The results of these approaches must be analyzed for building another typology of normative links. Such links can be found between legal norms in particular through their inter-citation and hierarchical system [17], [18].

They are also found when considering the occurrence of some fundamental concepts in legal texts: for example the notion of “water resource” will be found in many legal texts like the European Water Framework Directive, the French law on water and aquatic environments of 2006, etc. or in sub-parts of these texts, exhibiting some cognitive patterns, the strength of which can be quantified using information functions [19]. Mining large corpuses of legal norms in search for some notions that are central in an ontology design for water resources, will clearly exhibit this organization of the “water norm system”.

3.5 Connecting Sub-systems

To each sub-system just described is associated a representation as a set of entities (vertices: resources, agents, actions, norms) related by different types of functional links (edges between some pairs of vertices). For the sake of clarity, in Figure 1, these sub-systems are represented as vertices of a kind of meta-network that encompass all the platform items; the links represent classes of links that in fact should be detailed, and that connect not only large sub-systems, but some vertices contained in the sub-systems. Let us give an illustration of the possible interpretation of these classes. Some of them get an apparently trivial interpretation. Each agent has the capacity to perform various actions on the resources (link “agent to action”). At this stage, the actions considered in the MAELIA Platform directly affect the resources (link “action to resource”). Many norms are regulating actions (link “norm to action”) with respect to their potential impact on the resource (link “norm to resource”), or conversely modify the possibility of action because of some particular state (water quantity or quality) of the resource. Some norms give a mandate or the power to some agents (link “norm to agent”) to realize some action. Some of these agents are also giving the right to create new legal norms (link “agents to norms”).

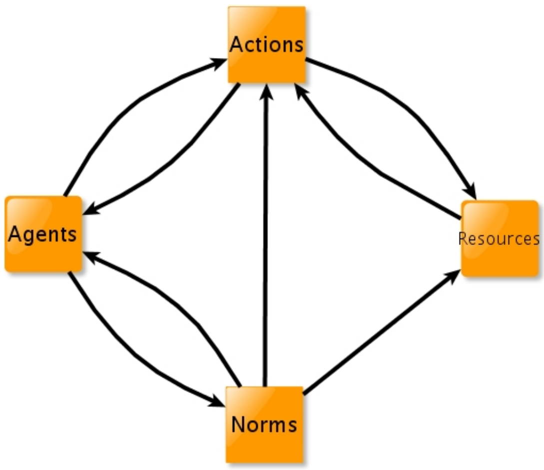

Fig. 1. A meta-network representing the MAELIA platform. “Agents” stands for the sub-system of individuals and institutions linked by various social and institutional ties; “Actions” stands for the sub-system of actions, “Norms” stands for the sub-system of legal and social norms and “Resources” stands for the sub-system of the water resource and other natural resources all linked by ecological or environmental dynamics. Arcs describe the different interactions which are detailed in the text.

We have also shown previously that some actions are related to other actions because of some conditional dependence (links internal to the sub-system of actions). But some conditional dependences exist also between some actions and agents: for example when an action performed by an agent requires one or several other agent to be available for cooperation. Some links between action and resources also exist: the production of hydro-electricity is possible if and only if some water is in the dam. The representation of such conditionality is included in the Figure 1, with the link oriented from the action to the agents, and the link from the resource to the action. Here we do not intend to give an exhaustive illustration of all the possible links that will be represented in the MAELIA Platform. This will be presented in another study.

Of course this representation as a complex network composed of sub-network defined on the basis of the knowledge that we have in different disciplines on the regulation of the environment and resources with norms, does not encapsulate all the complexity of the system. Indeed the different parts of the platform must be carefully instantiated and the information flux controlled.

4 Networks and Scenarios Building

The complex system represented in Figure 1 can be studied, from a mathematical and computer science point of view, by graphs and more precisely by weighted directed graphs with different kinds of edges.

4.1 Network Design

The approach we are developing allows us to use and develop tools from graph theory and network analysis to study the structure of this complex system. We briefly describe now some tools used in network analysis; the purpose of such an analysis is to better understand the structure of a graph [20].

A first step in network analysis is to compute some indices on the graph that are some quantitative measurements well adapted to characterize network structures. This measures are for instance the density of the graph (the ratio between the number of edges in the graph and the total number of possible edges), the local clustering (the probability that two vertices are linked knowing that they are already linked to a common vertex) or the global connectivity (how many intermediaries are necessary to connect any two vertices in the graph). A well-known structure may emerge from the analysis of the given graph such as a small-world structure.

An interesting feature is highlighting important vertices, respectively to the considered network it can be an important agent, an important action, an important resource or an important norm. However this notion of importance must be defined. In graph theory there are mainly three such notions called *centrality* [21]. The *degree centrality* is just defined as the number of links incident to a vertex; more the vertex is connected with other vertices, more important is this vertex. The *betweenness centrality* measures the number of shortest paths going through a vertex; a typical vertex with a high betweenness centrality measure is a vertex with a low number of links but linking two almost-disjoint groups. The *proximity centrality* is computed from the mean distance from a vertex to other vertices; an important vertex for this notion of centrality is a vertex able to reach quickly other vertices.

A fundamental aspect of network analysis is the research of communities. The notion of community, quite natural in a social network, can be extended to any kind of network as a group of vertices highly interconnected. Finding communities permits to have an overview of the network by aggregating the vertices into communities, therefore it permits to better understand the network structure, and also to draw an intelligible representation of the network [22]. These analyses can be first performed on each sub-system of our platform by adapting the classical notions exposed above to weighted directed graphs with different kinds of links. Then, the dynamic aspect of these systems should be taken into account; by measuring the evolution of centralities and other measures on the network; these evolutions may help us to construct dynamic models of the considered systems.

The analysis of the whole system drawn in figure Fig.1 and involving four different sub-systems exposed in Section 3 may reveal important and hidden features like communities. Indeed the sub-systems of resources, agents, actions and norms can be considered somewhat as homogeneous groups of entities linked by specific relationships and formed during the cognitive process of the model design. It is an analytical view of the water management system regulated by some normative system that is very pertinent when conceiving and implementing the platform, or when analyzing real water management systems. But we are not a priori guaranteed that these groups are also communities in a graph or network theoretic sense, when considering the whole system of Fig. 1. Even if the definition of a community in such a system is far to be obvious, it will be interesting to search for and find heterogeneous communities, that is the ones which gather vertices from several kinds of sub-networks and thus going through the predefined organization in four sub-networks. Though we already suspect that such hidden community exists, we would like to bring some evidence of their existence in such complex system and analyze their content. Equipped with the network approach and analysis we can potentially achieve this goal.

4.2 Scenarios and Social Engineering

An important purpose and a cornerstone of the MAELIA platform concerns the building of various scenarios by modifying a part of the system like addition/deletion of edges or vertices in its underlying network structure. These vertices or edges are chosen following two competing procedures: they can be chosen according to their centrality measures or they can be chosen at random, the latter one permitting to evaluate the real impact of the former one. Let us give two examples of scenarios that will be explored.

We shall first focus on the normative sub-system since one of the objectives of the MAELIA project is to simulate and assess the impact of different normative systems designed for the water resource management on the same socio-environmental system (see the end of Sec.2.2). A way to control some perturbation of the normative system is to change its network structure (for example removing or adding some links of a definite type). In other words, what are the impacts of a modification of the normative sub-system and/or links between its components and the other parts of the whole complex system? Is this perturbed normative sub-system inducing some better performances in terms of social development or resource sustainability (all concepts to be precised, even if competing definitions are retained)?

We also plan to consider governance issues. A very abstract and abridged way of representing the governance is to draw the set of agents (in our case public agencies and authorities, stakeholders, etc.) linked by different types of relationships of interest for the governance of the water resource at basin scale. In a top-down controlling system of the decisional power, no link will go from the bottom vertices (agents with no recourse for participating in any decision) to the upper vertices, say to agents having a real capacity to take decisions concerning the management of the resource. Adding a few link going bottom up, or even directly creating a kind of short cut, from the bottom most stakeholders to the powerful decision-makers, should deeply change the various centralities of all the agents and consequently the effective mechanisms of decision-taking. Such idea have been for example analyzed in the case of the environmental governance [23] but not analyzed with mathematical tools and quantitative measures as we plan to do in the MAELIA Project.

5 Conclusion

In the MAELIA Project we are building a multi-agent platform for assessing the impact of environmental norms on the environment, water resources and socio-economical dynamics. We here proposed an architecture of the MAELIA platform based on a meta-network structure. The understanding of the functioning of this complex system passes through the study of network dynamic measures and the research of heterogeneous communities. In this paper we explain the various analysis and scenarios building that will be now possible. Several hard problems found in the theory of organization, in the analysis of environmental and resource governance, in the impact assessment of legal norms, etc. can be addressed in a rigorous way using this particular approach.

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