Using Agent-Based Simulation to understand the role of values in policy-making

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Abstract. We propose to explore the role of values in policy-making and the use of ABS for elucidating this role. In this paper we outline a conceptual framework for value-driven modelling of public policies and illustrate it with an agent-based simulation of irrigation practices.

Keywords: agent-based simulation, policy-making, policy values

1 Introduction

It is generally acknowledged that policy-making is about achieving a better state of the world and, consequently, at design time, it implies that policy-makers make choices based on values [14,46]. However, the actual effects of those choices are difficult to assess, since the real world is complex [25]. Moreover, policy-makers need to address trade-offs between the conflicting interests of the several stakeholders at the run-time. We postulate that one way to deal with this complexity is to elucidate how values are involved in those decision-making processes.

For this purpose, we are following a threefold strategy: (i) first, we develop a theoretical framework that articulates the interplay between the activities involved in the policy-making cycle and the value-based choices of the main stakeholders; (ii) second, we propose to use agent-based simulation (ABS) to visualise the relationships between policy goals and instruments, on one side, and the behaviour of those agents for whom the policy is intended, on the other; (iii) third, we focus our attention on a specific policy domain —the use of water in agriculture— in order to draw inspiration from realistic examples, have access to empirical data and expert advise, and develop guidelines for a wider application of our proposal.

In this paper we show how ABS may be used to explore the role of values in the agenda-setting stage of the policy-making cycle. More specifically, we outline our conceptual framework in Sec. 3 and its background in Sec. 2. In Sec. 4 we discuss a model that illustrates the gist of our proposal. The model is based on actual agricultural data and practices but we present a simplified form to demonstrate the interplay between two policies —based on different values— for regulating irrigation practices in a community of farmers whose individual decisions obey different value sets. After the discussion of this example we identify some key challenges and sketch our future research plan.

2 Background and State of the Art

2.1 Values and behaviour

Values are at the core of decision-making, motivations, preferences, and attitudes [35]. Schwartz *et al.* [42] defined values as "concepts or beliefs, about desirable end *states* or *behaviours*, that transcend specific situations, guide selection or evaluation of behaviour and events, and are ordered by relative importance".

Rohan [38] alerted to the definitional inconsistency of the 'value' construct. Nevertheless, a **common** point in the literature is that values play an active role in the intentional human behaviour and decision-making —regardless of whether the reasoning about them is conscious or not [37].

This leads to the postulation that individuals hold distinct *rationalities* [43]. Decisions are taken because they serve the values of an actor *as the actor sees them* [1]. Besides values, they use other constructs, such as mental models, that are simpler representations of the environment that are used to understand and interact with it [26] and make explanations and inferences of diverse phenomena [9], and often are incomplete and biased [26,17,5]. We assume, therefore, that agents hold mind-frames, generated by values and other constructs, that support decision-making. So often, as other socially developed constructs, they are collectively held [18,17,29].

There is no consensus on the categories of values in the literature. We identify, as fundamental categories, (i) *individual values*; and (ii) *social values*. *Individual values* refer to those values towards satisfying needs and self-esteem [39]. In contrast, *social values* are values values of society at large, concerning public interest or contribution to well-being, that emerge from the society or social group [29], and that would include also desirable properties with regard to governance [41]. However, this emergence is not trivial. When referring to social values of a single agent, we suppose that he assumes other subjects' minds [15] in the group to proceed with such emergence (although this social value is not consensual). In short, individuals have beliefs about what defines the well-being of a society altogether and how public affairs should be governed in order to achieve a good social outcome (that is, many individuals *live well*), and these may be incompatible with their individual values. In fact, we believe that the framework presented in this paper, including participatory modelling and negotiation, becomes a tool to facilitate such emergence of social values.

2.2 Values in policy-making

In broad terms we understand policy-making as a process in which a group of agents, that we call *policy-makers*, design, enact, and evaluate a set of instruments to govern the activity of other agents, that we call *target agents*, within some domain of activity [46]. A policy is devised in order to *govern* the activity of target agents towards a state of the world that is deemed desirable by policy-makers as well as other relevant stakeholders [30]. Hence, governance is achieved through *means* like norms, incentives, and programs, towards *ends*, or intended outcomes of the policy. These policy ends are usually represented by some performance indicators or metrics that serve to assess whether the policy means are being successful [24].

Values and beliefs of policy-makers are reflected in policies [16,46,14]. According to Stewart [46], "policy design has a value-based component because the ways we attempt to change or influence behaviour depend on, in turn, beliefs about the reasons for that behaviour". In other words, the choice of policy means and ends reflects the mind-frames of policy-makers, since the policy-makers' values serve to determine whether a world state is better than other and whether specific means and ends are coherent or responsive to those values. The adoption of a policy, on the other hand, depends on the decisions that target agents make, thereby involving their mind-frames and, in particular, their values [30,27,13].

We assume that policy values [10,46,48] are instantiated as means and ends according to their makers mind-frames. We adopt a consequentalist approach, that is, reason about values through their effects, with regard to *means* that achieve such effects and *ends* that reflect those values.

2.3 Reasoning with values

In summary, values are projected onto behaviour and the state of the world. Therefore they are reflected on governance and individual and social decision-making models and metrics.

We recognise that values are incommensurable and, therefore, they cannot be directly compared; which leads to value conflicts [1,47]. As mentioned, values are ordered by relative importance [42]. It is a mechanism to avoid value conflicts and guide decision when facing a trade-off. Thus, typically, value profiles are represented by rankings.

It has been suggested to use several utility functions for each agent [1]. According to Simon [45], actors do not aim at choosing the best solution, but rather they accept satisficing solutions. Thus, we could infer that behaviour emerges from diverse satisfying functions in distinct situations.

Also, we assume that policy-makers reason on values by means of argumentation. Some work have approached practical reasoning in argumentation frameworks (for instance [50,3]). Not to mention the role of values in design (as in [28] for policy-making and in [31] for computational modeling)

2.4 Simulation in policy-making

Because of the complexity of policy-making, the use of simulation in policy design has been advocated to reproduce the dynamics of an artificial system so as to observe their behaviour and afterwards draw inferences and conclusions [21]. It makes possible to explore alternative policies without committing resources and disturbing the real social system, which produces useful evidence in order to identify successful and counterproductive pathways in policy-making [4].

Agent-based models for social simulation (ABS) are a powerful approach to this end [25]. Basically, an agent-based model (ABM) generates an "artificial society" from empirical knowledge that will be deployed for computational simulation [22,20]. Ideally, these models capture the variety of decision-makers that interact within the system, which is particularly useful to constitute agents with distinct mind-frames as aforementioned. ABS enables to explore the effects of policies' implementation in the system.

Agent-based simulation has been used to study diverse policy domains: water resources management [7]; land-use changes [34]); agriculture [40,6]; programmes enrolment [44]; and R&D policy [2], among others.

2.5 Water as policy-domain

Policy-making aims to solve societal problems and intervene on the system accordingly. Water, as an essential resource, is always at the heart of social and ecological conflicts, which are aggravating due to the global change [12].

Water management —activities and processes to provide services safely— and users have an impact across the whole socioeconomic and ecological system.Consequently, water breeds disagreements and conflicts, as water management imply value-laden decisions, trade-offs, and ethical judgements (see, for instance, [33,51,11,8,23,16,49]).

We believe that water policy domain involves a rich repertoire of challenges (value-driven decision-making; collective agreement, policy design, negotiation, etc.). Therefore, it fits perfectly into ABS for policy-making taking into account the role of values.

3 An Outline of a Conceptual Framework

We presume that values play a substantial role in policy-making. To this end we propose to develop a conceptual framework to represent *policy-making as a value-driven social coordination process*. The core of this proposal is outlined in Fig. 1.

In broad terms, we postulate that policy-making involves *collective processes* where policy-maker agents *institute means and ends* in order to *influence the behaviour* of target agents to achieve a *better state* of a relevant part of the world. We say that these processes are *value-driven* because the choice and assessment of means and ends reflect the values of policy-makers, while the behaviour of target agents responds to their private values.

We can be more precise:

1. **Policy-making processes are a subclass of socio-cognitive technical systems** (SCTS) [32]. Consequently, a policy-making process $\mathcal{P}$ has the following features:
   - **s.**1 $\mathcal{P}$ is situated in a physical/socio-economic context and it organises and refers to activity and entities of a limited relevant fragment of that context: the *policy domain*
   - **s.**2 involves a class of stakeholders that contains at least two distinctive roles: *policy-makers* and *target* agents;

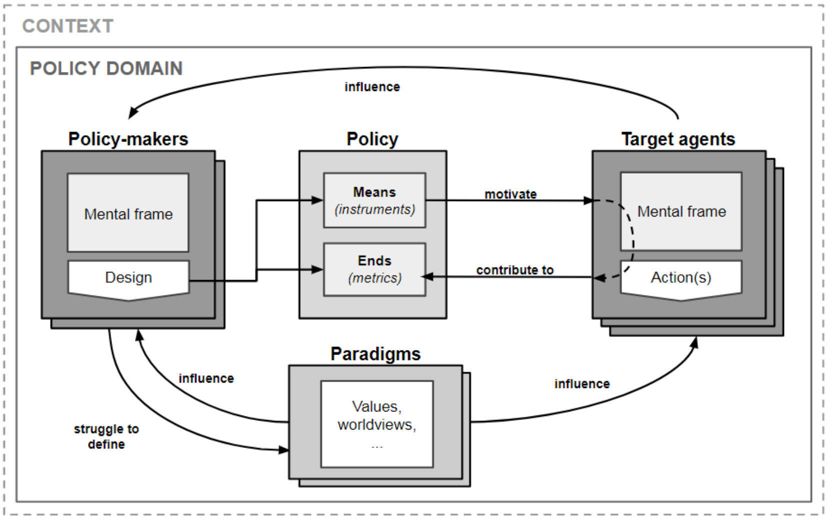

Fig. 1. Distinctive features of policy-making as a value-driven socio-cognitive system

s.3 agents behave according to their own *mind-frames*, which include personal values among other mental constructs;
s.4 a *policy domain ontology* that is the same for all stakeholders;
s.5 an observable *shared state of the world* that is altered by events and actions;
s.6 actions are *conditioned* by physical an normative constraints but they may be further constrained by norms and conventions whose compliance and enforcement is determined and applied by stakeholders;
s.7 agent interactions are organised in policy-making *action arenas* [36] ("scenes" [19]). We distinguish three (that reflect the "policy-making cycle"):
   (i) *Policy definition:* Policy-maker factions negotiate their preferred policy means and policy ends and agree on an instrumentation of these: on the one one hand, as a set of new affordable actions, the norms that regulate them, and the incentives and persuasion strategies; and on the other hand, the metrics that are to be known by relevant stakeholders.
   (ii) *Policy enactment:* Target agents perform afforded actions in the world of interest subject to the policy-related norms and alter the state of the world. Target agents may act individually or collectively. Each agent has its own mind-frame that conditions its behaviour. In particular, individuals have their own values and metrics associated to their individual actions and the social outcome.
   (iii) *Policy evolution:* Target agents may become aware of desirable changes in policy ends and means and negotiate among themselves and eventually with policy-makers.

2. **Policy-making processes are value-driven** (see Sec. 2):
   v.1 *Assumptions about values:*
   - We hold a *consequentialist* view of values. This entails that values are meant as their effects and thus may be *projected* by individuals or groups onto policy means (a norm ϕ or an action μ that promote value α and demote value β), and policy ends (world state σ is better than state τ according to value α).
   - We distinguish between *private values* that are held by individual agents and collective agents and are involved in their decision-making; and *public values* that are involved in the assessment of the "goodness" of actions, events, facts, governance means and states of the world.
   - For both types above, we distinguish between *individual* and *social* values. The first are held by individual agents and the second are attributed to social groups.
   - We do not require that values are commensurable and do not commit to the existence of forms of aggregating individual and *social values.*

   v.2 *Policy schema:* is the explicit expression of the use of values in the way a policy will be instrumented and assessed. We distinguish two main constructs:
   - *Policy means* aim to produce a behavioural change on target agents. They essentially define a set of *institutionally affordable* actions, that is, the new ones that target agents will be enabled to perform. These policy means are supported by *instruments*, such as incentives, norms, and persuasion discourses, that intend to foster the activity of agents towards the policy objectives.
   - *Policy ends* define desirable future states intended to be achieved by the policy and are specified through a set of *metrics* to evaluate the evolving state of the social space.

   v.3 *Policy evaluation:* Policy-makers will draw on the policy schema to assess the success of a policy; however, agents may formulate additional ends and metrics (possibly kept private) and using the schema metrics and their own obtain a different assessment of the outcomes. These differences provide essential input for the policy evolution arena.
3. **Paradigms and mind-frames:**
   p.1 Paradigms [33,13] consist of social values, norms and practices, as well as a shared ontology that recognises facts and actions and allows for intelligible representations of the world. A paradigm is somehow assumed by society and its members and is thus reflected in individual and collective worldviews and mind-frames.

   p.2 Paradigms are instantiated as *policy paradigms* that constitute self-legitimating worldviews adopted by policy-makers and target agents.

   p.3 In the policy definition arena, policy-maker factions strive to steer public policies according to their mind-frames. Factions may try to redefine paradigms.
4. **Uses of the framework:**

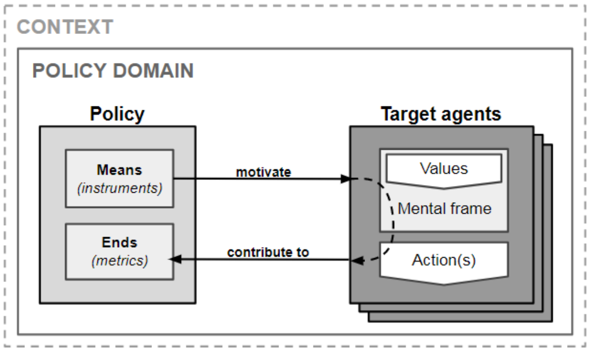

Fig. 2. Simulation of the enactment of a policy schema. Arrows represent simulation submodels (perception, social interaction, decision-making, etc.)

u.1 The framework is intended for a designer or policy-maker to develop a model of a policy-making process in a given domain (we refer to this as the *real world model*). Roughly, it serves for structuring the elements of the SCTS: policy-maker factions, target agents with their values and frames, policy domain governance infrastructure and policy schemes. It may have descriptive (understand the policy domain) or prescriptive roles (support the implementation of a policy schema).

u.2 The model may then be turned into a specification for implementing an agent-based or participatory simulation that may be used to understand a policy domain and explore potential interventions. Although all arenas may be part of the implementation, the policy enactment arena is the one where ABS has proven most useful. Fig. 2 depicts the core elements of the conceptual framework involved in the simulation of enactments.

u.3 The model may provide the grounds for a **policy-support systems** to negotiate, monitor and adapt an actual policy. Simulation with the enactment arena of a policy schema may be used by factions to support off-line negotiation or (agent-supported) argumentation in the definition and evolution arenas .

Whenever we speak of agents in this section we have the possibility of software agents in mind. In particular, our definition of *policy schema* is based on the possibility of automating reasoning about values when they are projected onto means and ends. Moreover, the boundaries we envision for the enactment arena are such that the main simulation input for this arena are a policy schema and a population of target agents. This facilitates experimentation with the interplay of agent mind-frames and means/ends combinations.

4 An illustrative exercise

We have developed a toy model to illustrate how the presented framework may be used with ABS for policy-making in the water policy domain.

4.1 Model

The model represents a community of (only) farmers. Farmers withdraw water resources from a watercourse, use them to irrigate a crop, and sell their production to earn money. It rains, which provides both farmers and the watercourse with resources.The object of the model is to test policies (introduced as norms and actions) to observe their effects on the environment/social space (as water resources and socio-economy) and on the acceptance of farmers.

Target agents: Farmers are characterised by the following attributes: (i) *mind-frame*; (ii) *farm size*; (iii) *money*; and (iv) *crop water requirement*. Also, farmers are capable of (a) *cultivate their farm*; (b) *expand* their farm; and (c) *leave* the farm. With regard to (a), farmers demand water to supply those fraction of the crop requirement —calculated as the reference evapotranspiration multiplied by a crop coefficient— that is not provided by the soil of their location.

A farmers' *mind-frame* can be either *environmentalist* or *productivist*. Farmers that subscribe to productivist values focus on their *money* and the satisfaction of their irrigation demands. In contrast, *environmentalist* farmers focus on their *money* (to a lesser extent) and on the nature (i.e., on the volume of water in the watercourse). Here, in fact, we are assuming that target agents have private metrics.

The *mind-frames* (and values) determine the farmers' happiness, which is modelled as a dichotomous state. Moreover, it also affect how farmers behave with regard to norms and institutions and therefore how they react to policies. *Happy* farmers irrigate complying with water constraints, provided these are in force. However, *unhappy* farmers adjust their behaviour in order to improve their chances to be happy. For example, *productivist* farmers ignore water constraints according to a probability, as long as they have less than a minimum amount of *money*; moreover, when they have enough *money*, they invest to increase their *farm-size*, insofar as it is allowed. In contrast, *environmentalist* farmers always comply with constraints and when they have enough *money*, their water withdrawal is only the half of their actual demand.

Scales: The model simulates three decades of activity through discrete one-year steps (although some processes are executed using one-month steps). Each month it rains, water flows, and farmers irrigate. Each year, farmers harvest and sell their production and assess their happiness.

The spatial scale of the model represents a watershed where farmers share a water source. The land is represented with square patches. Patches have coefficients that are used to calculate the water runoff and the percolation. Precipitation and evapotranspiration are constant, uniform across the watershed, and distributed over the year by months (for example, in summer, it rains less and evapotranspiration is higher). We model the watershed as two inclined rectangular planes that discharge into a water channel in the middle. The whole watershed discharges into a point where is placed a flowmeter.

Policy-schemes: We have defined two different policy-makers factions. Both factions coincide in the fact that irrigation agriculture is desirable for the public interest —which is the *paradigm* for all factions. Therefore, the policies include as *means* the action that farmers can irrigate their crops and sell their production for their own profit.

Policy P_1 embraces utilitarian values such as *productivity* and *wealth*. It focuses on the rural development of the basin, understood as the growth of farm industries and the wealth they generate (*end*). It considers that promoted values may be measured as the average economic resources of farmers (*metrics*) —although there are other options; for instance, the total farming area of the basin. In parallel, the policy posits that the desired state is achieved when farmers can irrigate with low restriction and they are able to expand their farms at their will (*means*).

Policy P_2 holds environmentalist values such as *conservationalism* and *fairness*. It aims at keeping the watershed in good environmental conditions (*end*). It establishes that the flow of the watercourse should be regularly monitored (*metrics*), and they support this statement with scientific studies that define an environmental threshold. Consequently, farmers can irrigate, but they cannot expand their farms (*means*). Also, they cannot withdraw more than a certain amount of resources. Additionally, their turn for irrigation will be determined according to their money amount, and not by their location, as it was by default (*instruments*).

4.2 Simulations

The first experiment focuses on the comparison between policy (factional) values, instantiated and simulated as instruments and metrics. Namely, the simulation generates an output that aims at answering which effects on the world are produced by policy values and how these are measured.

Both policies are tested on an environment inhabited by given populations of target agents that hold value profiles. Let us assume that the value profiles of the population is 50 % *productivist* and 50 % *environmentalist*. Policy values of P_1 and P_2 are input into the simulation model as in Table 1.

The evolution of the simulated effects of both policies, according to the established metrics, are plotted in Figs. 3 and 4. As can be seen, the watercourse flow under P_1 has more acute seasonal variation, falling under the environmental recommendation repeatedly. In contrast, the average of the money of farmers rises faster under P_1, although the deviation is lower under P_2.

The simulation can be used to negotiate *instruments* in order to reach an *end* that satisfies both factions in a policy definition arena. Let us assume that they

Table 1. Comparison between policy values (as input for the simulation)

Input	P_1	P_2
Water constraint[1] (m^3/ha/year)	10 000	1 000
Farm expansion	Enabled	Disabled
Turn system (based on)	Distance	Money
Main metrics	Money (per capita)	Flow (m^3/month)

[1] Distributed equally per month.

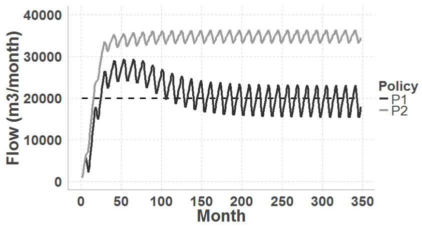

Fig. 3. Monthly flow evolution under both policies.

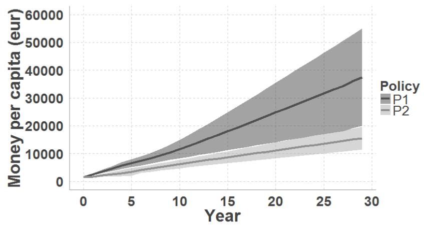

Fig. 4. Money (average and standard deviation bands) evolution under both policies.

reach an agreement with regard to the other *means* and therefore the policy (i) must enable the expansion of farms and (ii) must base the irrigation turns on the amount of money. They focus on the long-term effects (in this case, after 30 years) to negotiate the water constraint (Figs. 5 and 6). Observing the effects of policies, policy-makers could negotiate for a suitable water constraint, that would lead to the emergence of a consensual *social value*, as defined in Sec. 2.

The second experiment consists in the comparison between the values of policies and those of target agents. That is, given a policy, how target agents' support varies when altering their value profiles.

In this case, we do not simulate the effects on the world, but rather the acceptance of target agents (measured as the percentage of happy farmers). Considering the P_1 as input (Table 1), we change the population of *productivist* (M) and *environmentalist* ($E = 100 - M$) farmers to observe the outcome.

As expected, the more *productivist* the farmers are, the happier (Fig. 7). As we defined before, the policy values of P_1 match with productivist values. Therefore, the point of these experiments should focus on the acceptance when targeting at populations with diverse mind-frames. Curiously, when the population is completely *environmentalist* ($M = 0\,\%$), the amount of happy farmers is nearly 50 %. The reason is that farmers do not disturb the ecosystem in spite of having a low water restriction —remember that they irrigate only a fraction as long as they have a certain amount of money. However, whenever there are *productivist* farmers ($M > 0\,\%$), they use more resources —and even more when they increase their farms— pushing the *environmentalist* farmers to be unhappy.

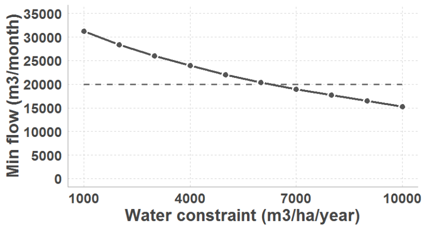

Fig. 5. Minimum monthly flow of the year according to the water constraint.

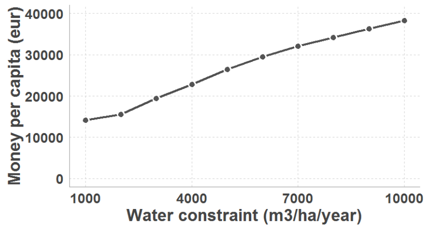

Fig. 6. Money (average) according to the water constraint.

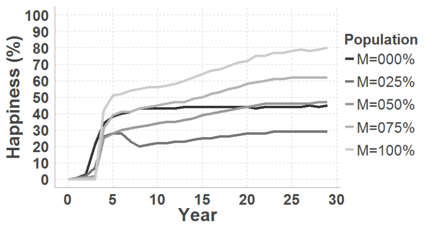

Fig. 7. Happiness (%) according to the mind-frames under the policy P_1.

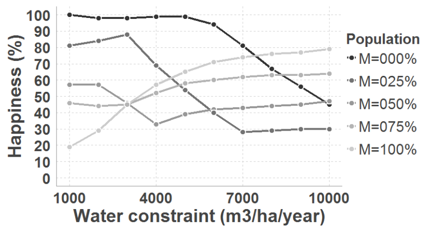

Fig. 8. Happiness (%) according to the mind-frames and the water constraint.

Additionally, we compare the acceptance of farmers (again modelled as *happiness*) with water constraints for diverse population profiles (Fig. 8). Predictably, opposite population profiles have curves with slopes of opposite sign. When the population subscribes completely to environmentalist values, the constraint that leads to full happiness is that one promoted by P_2. On the contrary, a productivist population is more happy with low constraints as under P_1. Nevertheless, the latter does not achieve full happiness: as all the farmers increase their farms, they demand more water resources to the point that the water ecosystem cannot provide them with enough water.

5 Closing Remarks and Future Work

We are interested in understanding the role that values play in the policy-making process and propose the use of agent-based simulation to support value-driven policy design. In this paper we have two specific objectives in mind: first, to outline a conceptual framework that represents the policy-making process as a type of socio-cognitive system; one where values are projected onto policy means (afforded actions and their governance mechanisms) and policy ends (metrics and performance indicators that evaluate the effect of agents behaviour on the state of the world). Second, to illustrate how agent-based simulation may be used within this framework to model water-use value-driven policy design.

We have the intuition that policy-makers can achieve a crisper understanding of the consequences of their proposals by making an explicit link between their values and the instruments and expected outcomes they choose. Such explicit links respond to a consequentialist view of values and aims towards a representation of incommensurable values that is ostensible and operational. The end goal is the expression of policy schemes in a manner that should be useful for negotiation among stakeholders, for fine-tuning instrumentation, for better adoption, and for transparent evaluation, follow-up and adaptation. Hence, this framework may contribute to identify where are major disagreements, either in the policy design (ends, metrics, means, or instruments) or the implementation (causal links or expected effects). Given that factions are not single players in the world, they should acknowledge others' interests or values so as to negotiate —and identify which values can be negotiated and which cannot.

Our intention is to further explore policy-making and values in the water policy domain, as it involves multiple values and multiple stakeholders [48]. We assume that the socio-hydrologic space can be modelled as a socio-cognitive technical system [32], and that the opportunities in the development of socio-cognitive agents are substantial and non-trivial [15,32].

We foresee the following lines of work:

- Reasoning with values and about values: value aggregation, value comparison, values and norms; values versus goals and preferences.
- Developing the notion of policy schema: what are the useful instruments to model? How can means and ends be represented in order to simulate reasoning about them? How are norms related with values?
- Modelling the policy definition arena: Choosing a reference case. Use of value-based argumentation. Negotiation as conflict resolution? A coherence-based analysis of faction values and actions.
- Explore second-order reasoning in the policy-evolution arena.
- Addressing empirical questions like: Which values are relevant in this domain? How to measure them and build a "scoring methodology"? How to translate information given by (target) agents into satisficing functions? How target agents assess simulated outcomes?
- Explore the usability of the framework: the interplay between the number of afforded actions and values in dispute. Negotiation with ABS support.

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