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Participatory modelling for the integrated sustainability assessment of water: The World Cellular Model and the MATISSE project

Tabara, J. David; Wallman, Patrik; Elmqvist, Bodil; Ilhan, Akgün; Madrid, Cristina; Olsson, Lennart; Schilperoord, Michel; Valkering, Pieter; Weaver, Paul

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MATISSE

WORKING PAPERS

9

4/2007

PARTICIPATORY MODELLING FOR THE INTEGRATED SUSTAINABILITY ASSESSMENT OF WATER: the World Cellular Model and the MATISSE Project.

J. David Tàbara
Patrick Wallman
Bodil Elmqvist
Akgun Ilhan
Cristina Madrid
Lennart Olson
Michel Schilperoord
Pieter Valkering
Paul Weaver

MATISSE Methods and Tools for Integrated Sustainability Assessment

Series Editors:

Jill Jäger
SERI Sustainable Europe Research Institute, Garnisongasse 7/27, 1090 Wien, Austria, jill.jaeger@seri.at

Paul M. Weaver
Wolfson Research Institute, University of Durham, UK, pweaver@noos.fr

Authors:

David Tàbara (Corresponding author)
Institute of Environmental Science and Technology, Autonomous University of Barcelona, Campus UAB ; 08193 Cerdanyola del Vallès (Barcelona). Catalonia, Spain. Tel. + 34 - 93 - 581 2974; Fax + 34 - 93 - 581 3331; Joandavid.tabara@uab.cat

Patrick Wallman
Bodil Elmqvist
both: LUCSUS, Lund Universtity, Lund, Sweden

Akgun Ilhan
Cristina Madrid
both: Institute of Environmental Science and Technology, Autonomous University of Barcelona Catalonia, Spain.

Lennart Olson
LUCSUS, Lund Universtity, Lund, Sweden

Michel Schilperoord
Dutch Research Institute for Transitions Erasmus University in Rotterdam

Pieter Valkering
International Centre for Integrated Assessment and Sustainable Development University of Maastricht

Paul Weaver
Wolfson Research Institute, University of Durham, United Kingdom

MATISSE (Methods and Tools for Integrated Sustainability Assessment) aims to achieve a step-wise advance in the science and application of Integrated Sustainability Assessment (ISA) of EU policies. In order to reach this objective the core activity of the MATISSE project is to improve the tools available for conducting Integrated Sustainability Assessments.

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The MATISSE Working Papers can be downloaded at http://www.matisse-project.net/.

Preface

About the MATISSE project

The MATISSE (Methods and Tools for Integrated Sustainability Assessment) project is funded by the European Commission, DG Research, within the 6th Framework Programme. The project is interested in the role that Integrated Sustainability Assessment (ISA) could play in the process of developing and implementing policies capable of addressing persistent problems of unsustainable development and supporting transitions to a more sustainable future in Europe. The core activity of MATISSE is to develop, test and demonstrate new and improved methods and tools for conducting ISA.

This work is carried out through developing and applying a conceptual framework for ISA, looking at the linkages to other sustainability assessment processes, linking existing tools to make them more useable for ISA, developing new tools to address transitions to sustainable development and applying the new and improved tools within an ISA process through a series of case studies.

The extent to which the case studies are carrying out a complete ISA for their area of focus varies between attempts to cover all phases of an ISA process to partial implementation of the process. Equally, different case studies are oriented to developing and testing tools and approaches to some, but not all, of the methodological challenges of ISA. The case studies are complementary, however, and the set of cases offers the opportunity to address a wide range of methodological challenges and to explore linkages between cases. An evaluation of practical experiences with ISA implementation in the case studies will provide guidance on the further improvement of methods and tools. Results will also contribute to more informed policy advice.

What is ISA?

Within the MATISSE project, Integrated Sustainability Assessment (ISA) has been defined as a cyclical, participatory process of scoping, envisioning, experimenting, and learning through which a shared interpretation of sustainability for a specific context is developed and applied in an integrated manner, in order to explore solutions to persistent problems of unsustainable development. ISA is conceptualised as a complement to other forms of sustainability assessment, such as Sustainability Impact Assessment, Integrated Assessment and Regulatory Impact Assessment. Whereas these other forms of assessment fulfil the pragmatic need for *ex ante* screening of incremental sectoral policies that are developed within the prevailing policy regime, ISA is conceptualised as a support to longer-term and more strategic policy processes, where the objective is to explore persistent problems of unsustainable development that have a systemic pathology and possible solutions to these. ISA is therefore oriented toward supporting the development of cross-sectoral policies that specifically address sustainable development and at exploring enabling policy regimes and institutional arrangements.

MATISSE Working Papers

Matisse Working Papers are interim reports of project activities that are published in order to illustrate ongoing work and some provisional conclusions, as well as providing the opportunity for discussion of the approaches taken by the project and interim results. This discussion should be both within the project and between project members and the broader scientific and policy communities. Readers are encouraged to contact the authors to discuss the content of MATISSE Working Papers.

Jill Jäger and Paul Weaver

Editors of the MATISSE Working Paper Series

ABSTRACT

This paper describes the participatory process of developing and implementing a prototype model aimed at supporting the *Integrated Sustainability Assessment* of water resources and policy options at different scales. The model - called the World Cellular Model (WCM) focuses on the representation of *agents*' behaviours and their systemic relationships with their environment. This is achieved by examining the interests, motives, cultural beliefs and structural resources that drive agents' actions with regard to the use of stocks and flows of water, by looking at the impact of such water behaviours on the environment and on the natural ecosystems at different scales, and by examining in a coevolutionary way the impact of such environmental changes on the behaviours of agents. The WC model takes a 'total system', multi-scale, agent perspective. That is, agents operate in a single interrelated system in which each individual or collective agent responds to the availability and use of a set of stocks and flows of rules and/or institutions (S), energy and resources (E), information and knowledge (I) that in turn provokes environmental change (C) or impact on the social ecological system. . This model is being developed together with the use of participatory Integrated Assessment focus groups (IA-fgs) with real stakeholders to get insights about agents' behaviours and the possible architecture of the model so as to increase its socio-ecological robustness and policy relevance. Our research is part of the EU funded project Matisse (Methods and Tools for Integrated Sustainability Assessment).

Key words: Integrated Sustainability Assessment, water modelling, participation.

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PARTICIPATORY MODELLING FOR THE INTEGRATED SUSTAINABILITY ASSESSMENT OF WATER: THE WORLD CELLULAR MODEL FRAMEWORK

1. INTRODUCTION

This paper presents a model prototype and a process aimed at supporting the Integrated Sustainability Assessment (ISA) of the use of scarce natural resources such as water. ISA is an emerging field of policy support aimed at unveiling the limitations of current approaches to deal with persistent problems of unsustainability. The causes of such problems are the result of 'wrong' solutions to existing problems, in the sense that these are based on the application of non-systemic perspectives both in science and policy when dealing with issues which are, inexorably of a systemic nature. Such solutions create larger problems which then become more difficult to handle by the existing societal institutions in the next stage of development, often not yet adapted to the new socially created situation. Dominant tools and methods appraising development are often characterized by a monistic perspective, thus attempting to assess or explain everything by the single principle of growth and economic performance. Accumulative negative effects of development are usually ignored as are a handful of social, institutional and cultural factors, such as the role of knowledge and rules systems in the way society develops. Even the current discourse of sustainability has not yet been able to challenge the dominant development paradigm and so far has serve to guarantee and reinforce and extend the current institutional regime. A more transformative and integrative approach, based on a social learning process of searching and implementing alternative framings and conceptualisations to the persistent problems of unsustainability as well as of exploring possible pathways for individual and collective adaptive action is needed. Integrated Sustainability Assessment (ISA) is concerned with these challenges. Within the EU project MATISSE (Methods and Tools for Integrated Sustainability Assessment), we look at ISA not only from a theoretical perspective but in a pragmatic fashion by looking at the possibilities of developing and applying such alternative science-policy paradigms in several specific domains of policy action such as water management.

Within MATISSE ISA has been defined as:

> *A cyclical, participatory process of scoping, envisioning, experimenting, and learning through which a shared interpretation of sustainability for a specific context is developed and applied in an integrated manner in order to explore solutions to persistent problems of unsustainable development* (Weaver and Rotmans, 2005).

ISA needs to be distinguished from other approaches dealing with environmental and sustainability policy assessment such as Strategic Impact Assessment and Impact Assessment. In particular, the main distinctions can be summarised as follows (Weaver & Rotmans 2006):

Elements for analytical comparison	ISA	SIA/IA
Paradigm	Transition oriented	Incremental
Scope	Broad/multi-domain	Focused; single domain
Goal	Goal searching	Goal led
Approach	Holistic	Partial (example: only economics oriented
Process	Cyclical	Linear
Scale	Multi-level	Single-level
Stakeholders	Niche & regime players	Mainly regime players
	Takes account of emerging power	Only structural power is taken into account
Trade-off	Multiple trade-offs (A vs. B vs. C vs….) including values	Single trade-off (A vs. B)
Learning	Social learning	Cognitive learning
Ante-Post	Ex-ante process including scoping, visioning, agenda setting, experimenting, learning	Ex-post evaluation not including all these phases of ISA
Impacts	Impacts unknown	Impacts known

Table 1. Comparing ISA and SIA/IA

Hence, within the MATISSE project we see two different roles for sustainability assessment – one as a existing regime or paradigm applying process and one as a regime or paradigm exploring process. In Matisse, we are mostly concerned with the second approach, so that to develop approaches for exploring alternative paradigms to deal with unsustainability, putting the focus on systemic interdependencies, agency, participation and social learning rather than on forecasting known 'impacts'. Computer and expert tools such as models are being used heuristically and reflectively for these purposes and in our view, new tools and methods for sustainability assessment, in particular models, need to:

a) identify the relational causes of unsustainability. This process of identifying unsustainability involves an in-depth knowledge about the behaviour and the understanding of sustainability by a multiplicity of agents, and hence, new tools must be developed to incorporate and represent multiple perspectives and ways of reasoning.

b) build alternative pathways and scenarios capable to asses the possibilities to minimize, modify or eradicate the current drivers of unsustainability in an integrated systemic way. Drivers must be linked to and explain agents' behaviours.

c) enhance the possibilities for social learning by opening up the existing processes of co-production of knowledge and its application in the use of natural resources. This is an intrinsic and most fundamental function of tool development, and the reason for the inclusion of

stakeholders in definition the problem at stake (in this case, unsustainability). Sustainability assessment tools must support wide social learning, rather than becoming black expert boxes to forecast indisputable gloomy futures, however true are may be.

d) integrate both the social and biophysical factors that condition the societal adaptation to sustainability requirements, together with quantitative and qualitative knowledge (both from social and natural systems) by taking a relational integrated open systems perspective.

e) be based on interdisciplinary work and combines inputs from diverse social and natural sciences and has attempted at getting insights from stakeholders' behaviours, perceptions, and ways of reasoning from the very beginning of its development and in a participatory way.

A further assumption of our understanding of sustainability which affect the development of new ISA models is that these need to be based on the existence of *limits*. However, such limits are relative ones, not absolute, as they are dependent on human-environment relationships. That is, they are conditioned as much as on the evolution of social organisation, knowledge and technology, as on the constraints posed by the biophysical system. With regard to the latter limits, we are concerned about the depletion of natural resources and the capacity of ecosystems to absorb pollution to a threshold which makes it impossible for an ecosystem to provide services for human societies in the long term. Once such limits to the availability of resources or/and to the capacities of ecosystems to regenerate have been surpassed, we enter in a situation of unsustainability characterized by irreversibility.

2. MODELLING SUSTAINABILITY: EVOLUTION OF TOOLS

A brief review of the evolution of modelling human-environmental interactions (see boxes 1-3 below) reveals how over the last three decades the process has been toward simplification of the components depicted by the models and an increased representation of the role played by human agency (individuals, organizations, and other collective agents).

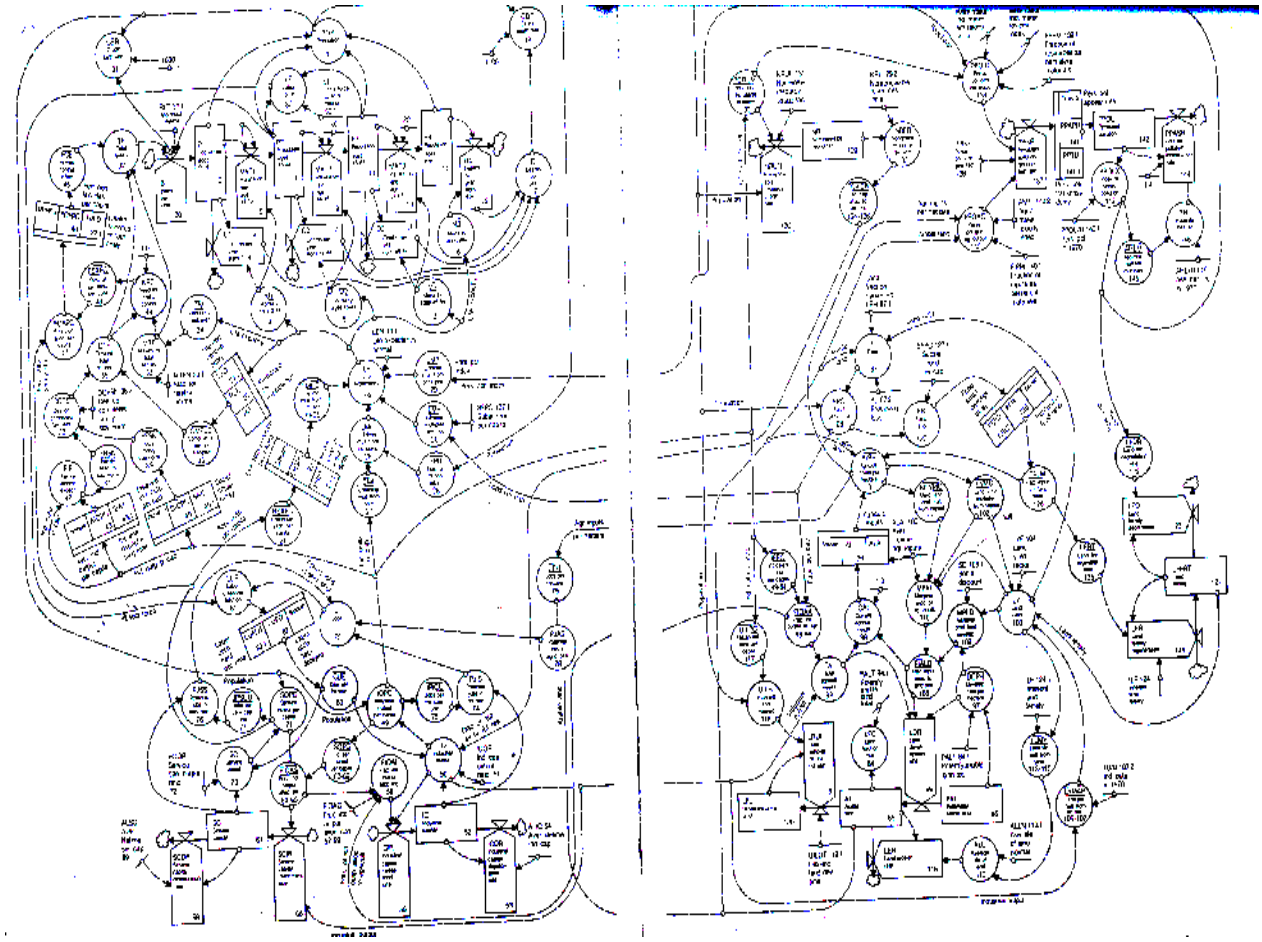


Figure 1. Early conceptualizations on modelling interactions between human and natural systems– I (from D, Meadows et al. 1972)

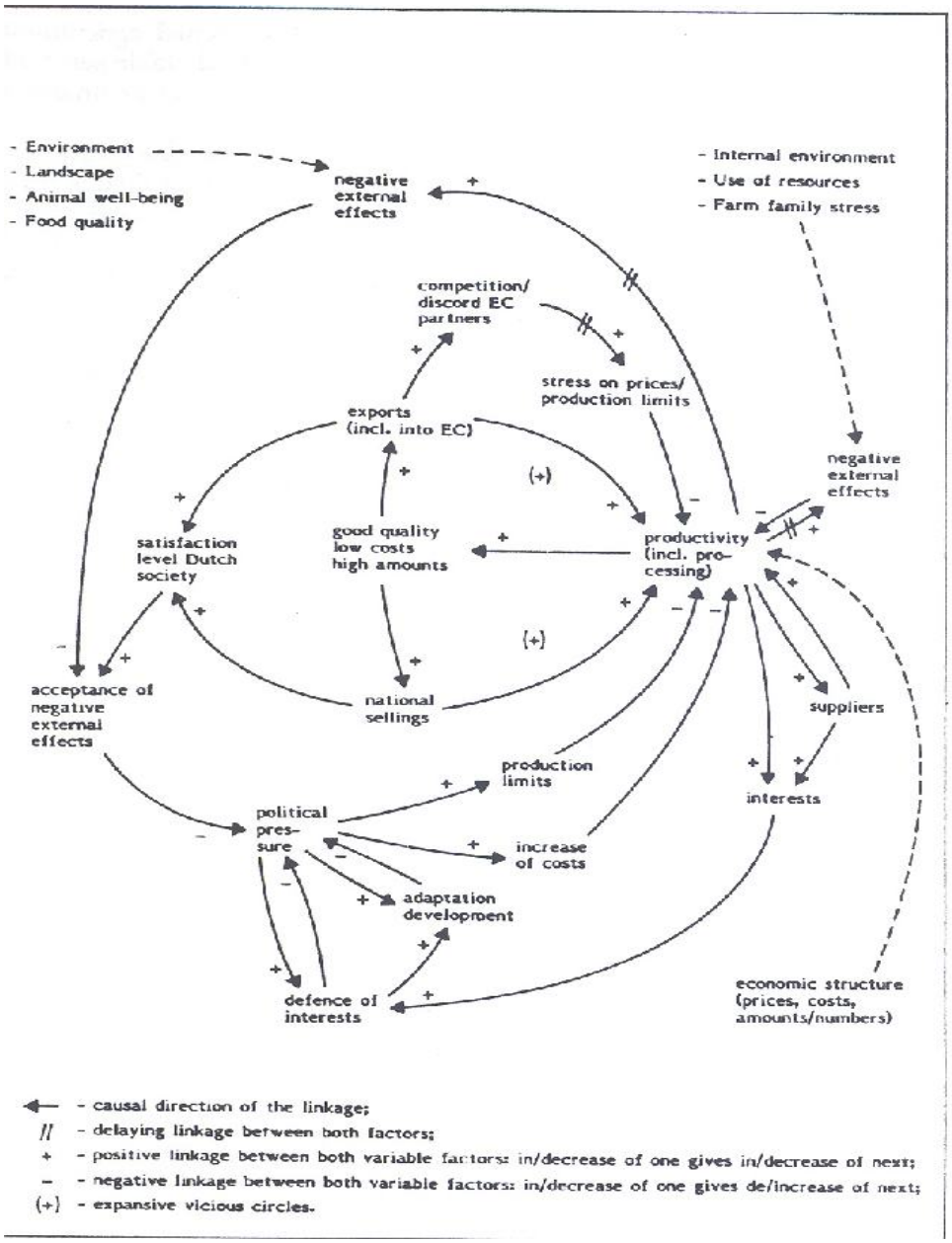


Figure 2. Early conceptualizations on modeling interactions between human and natural systems– II (from Wieringa and van Soest, 1985).

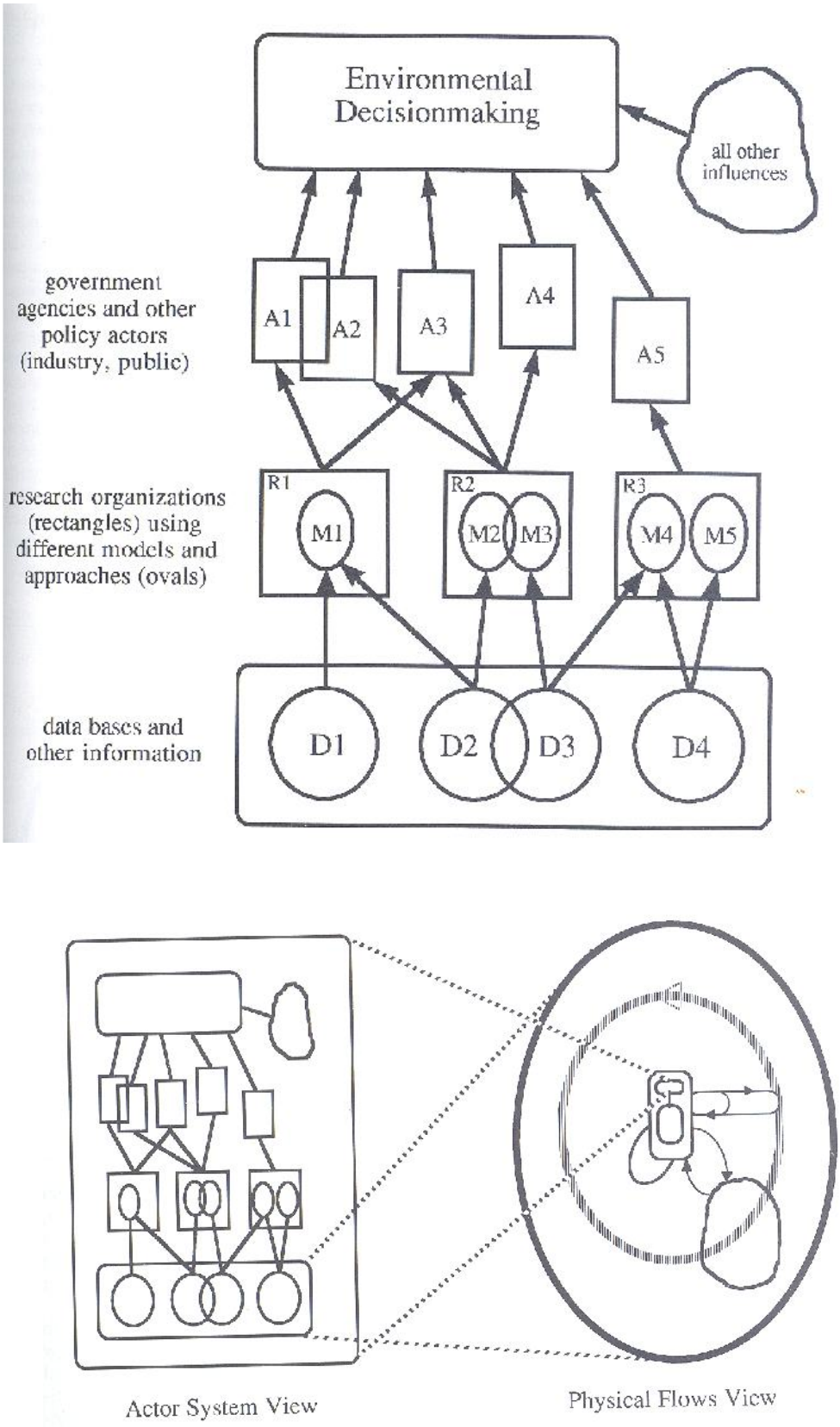
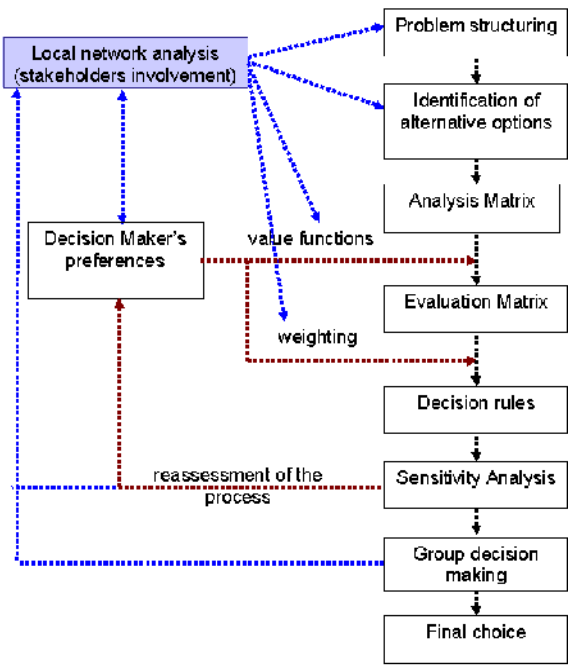


Figure 3. Early conceptualizations of modeling interactions between human and natural systems -III (extracted from J. Robinson, 1991)

In order to get insights about agents' behaviours, frame the problems at stake in a more relevant manner and enhance the social robustness of the assessments, modellers have increasingly opened the door to stakeholder participation. For instance, the Mulino Decision Support System starts by looking at stakeholders and decision making, and builds a process which is multi-sectoral for the assessment of the use of water resource at the river basin scale. Specifically, this supports the identification of pressures, assessment of impacts, defining the best options for the programmes of measurement and the involvement of stakeholders in the planning process (Figure 1) and does so in a participatory mode.



- Driving Forces (D): the underlying causes and origins of pressure on the environment
- Pressures (P): the variables which directly cause environmental problems
- State (S): The current condition of the environment
- Impact (I): The ultimate effects of changes of state, damage caused

Figure 4. The Mulino DPSIR approach (http://siti.feem.it/mulino)

Within MATISSE, the development of new methods and tools for the domain the sustainability assessment of water takes a participatory interdisciplinary approach (Tàbara 2006 (2003)). This is in line with the recent evolution of tools for sustainability assessment (Weaver and Rotmans 2006) which, in a nutshell, can be characterised from being:

- *supply-driven* *to* *demand-driven*
- *mono-disciplinary* *to* *inter-disciplinary*
- *technocratic* *to* *participatory*
- *objective* *to* *subjective*
- *certainty* *to* *uncertainty*
- *predictive* *to* *explorative*

And to which we add, as the most important recent development, the turn of emphasis of ISA tools:

- *From representation of biophysical change* *to* *representation of social agency.*

Participatory approaches to ISA modelling are understood to help providing a more accurate representation of social agents' behaviour and a more relevant socioecological robust depiction of the system of reference under consideration.

3. THE WORLD CELLULAR MODEL

Our task in the development of a new tool of the ISA of water has been carried out through several steps. First, we have carried out a series of Integrated Assessment focus groups (IA-FGs, Kasemir et al. 2003) with a sample of relevant agents in a selected river basin in order to gain insights about their behaviour and their visions of the (un)sustainability in the use of water resources. So far two stakeholders' workshops have been carried out, both in the Ebro river basin (Tàbara, 2006a, 2006b). Second, we have built a conceptual model, called the *World Cellular Model (WCM)*, aimed at providing a total social-ecological system perspective (Boulding, 1985, Tàbara, 2005) of the use and of the stocks and flows of water. The role of the WCM is to inform, from a theoretical perspective, current and future developments of the computing tool implementation and its interfaces, even though only a very few such applications can be made operational at present. Third, we have already started the actual implementation of the conceptual model in a computer environment together with an interface that can be used in participatory settings with stakeholders, such as in focus groups. Box 1 and Figure 5 give a summary of the conceptual content of the WCM.

Box 1: The World Cellular model, v.1.2

- The WCM considers the whole World water system as if there were only one single large river basin interconnected by continuous flows and stocks of real or *virtual* water (e.g., water contained in agrofood products).
- The structure of the social system in the WCM is composed of a set of agents, referred to as 'cells' or 'organs', each of them representing individuals, communities, river basin organisations or regions. Each agent depends on the availability of a minimum stock and flow of real or virtual water, referred to as 'kinetic water'.
- The water behaviour of each agent also depends on and is affected by its availability and use of energy (E), the norms provided by the institutional context or social structure (S), and the knowledge base and informational capital (I) which agents use to conceive the system. In turn, the use of water and energy stocks and flows by agents creates new coevolutionary impacts on the rest of the agents of system, in the form of new conditions for water use and socio-environmental change (C). This is refereed as the *SEIC* model.
- Flows and stocks of real and virtual water used by each individual or collective agent (cell) can be quantified and represented in terms of 'size'. Water interactions between agents can be assessed in a relational and integrated manner.
- The WCM should allow the assessment of the relationships between the dynamics of water flows and stocks both for quantity and quality. For instance, from a global perspective, increased flows in the form of real or virtual water lead to reduced stocks. A reduction of water quality tends to reduce the water quantity available to agents.
- Heuristically, water stocks and flows can also be divided into social, economic and ecological water stocks, depending on the main functions such stocks serve. The resilience capacity of water ecosystems depends on the maintenance of a minimum of water devoted to ecological stocks and flows. Similarly, the maintenance of economic and social dynamics depends on the maintenance of a minimum stock and dynamics of good quality water. In the first version of the model quality is represented to the extent it affects the total availability of water stocks.

- With GIS it is possible to spatially represent agents and the impacts on land use of increased (demand /supply) extraction or availability of virtual or real water by each identified cell' or 'organ' (e.g., the Ebro river basin) and compare the extraction and availability of related virtual or real water in other parts of the systems.
- The first versions of the WCM focus only on freshwater stocks and flows, and only at one scale (river basin) used by agents. Hence at present it does not yet take into account the marine waters or those waters not used or which do not take a key part of the functioning of the social system nor the links with the global water system.

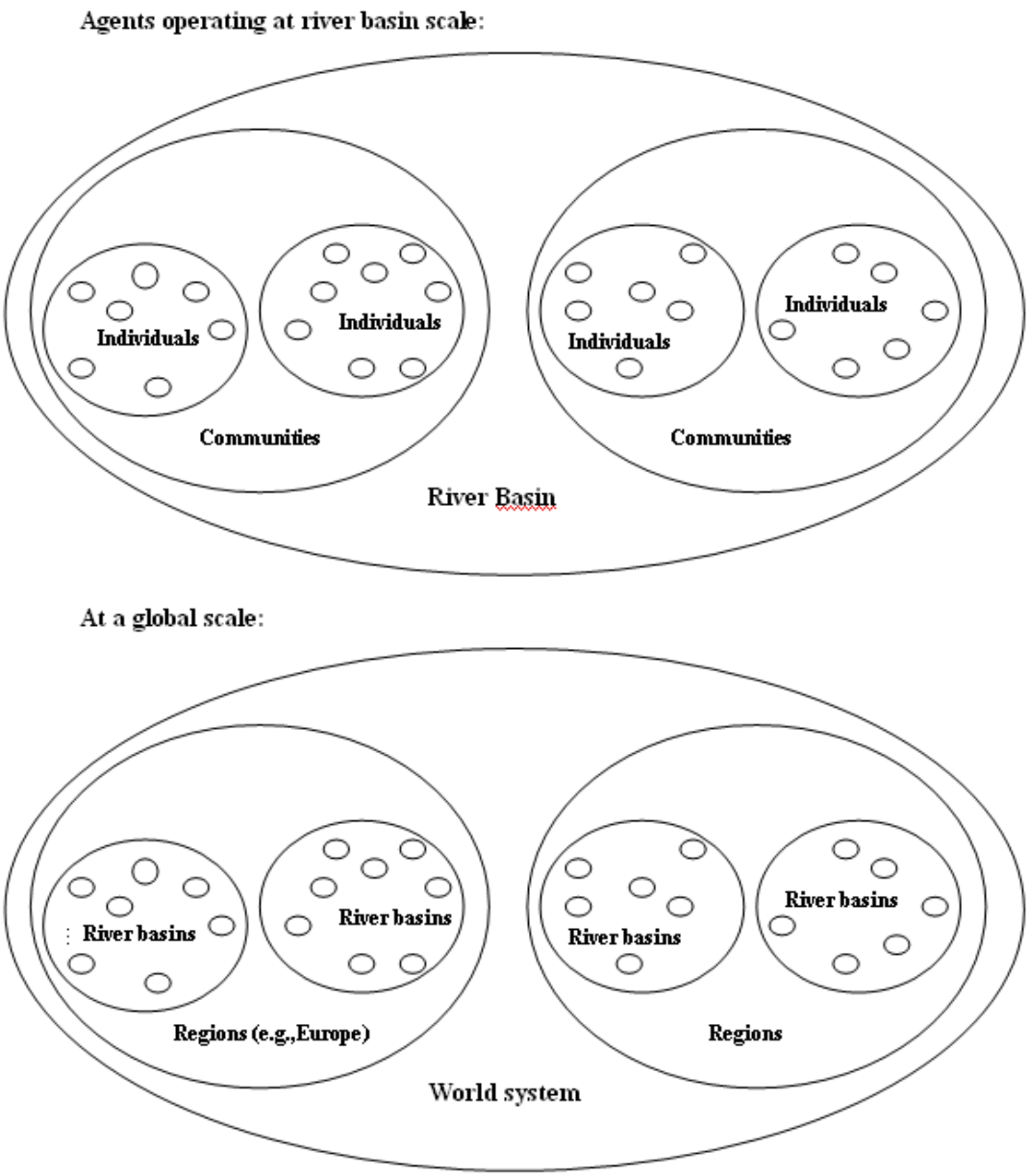


Figure 5. Agent representation in the World Cellular Model.

In the WCM *agents* are composed of a *set of cells*, which account for individuals, communities, river basin and regions. The cells exist in an environment that is characterized mainly by stocks and flows of real and virtual water. A cell's interactions with these stocks and flows (water movement and consumption, which are quantified in terms of the *size* of the cell) depend on the availability of *energy*, as well as *institutional* and *informational capital*. The water and energy use of cells create new *pressures* on the whole system (for instance, increasing CO_2 emissions, and thus changing the global precipitation regime). This "cellular" approach to systems modelling means, first of all, applying a *living* systems metaphor. For example, James Grier Miller (Miller and Miller 1978) argues that living systems exist at seven *levels*, each with characteristic structure and processes: cells, organs, organisms, groups, organizations, societies and supranational systems. Another feature of living systems is *structure*: accumulation of matter and energy in a region in physical space-time. As the parts of the system move in relation to one another, structure changes[1]. At the higher levels there are *emergent*, distinct behaviours that cannot be described only in terms used for systems below them in the hierarchy. "Cellular" approaches may also be linked to studies in *Artificial Life* and other fields based on the use of a tool called a *cellular automaton*, which is a model that consists of an infinite, regular grid of cells, each in one of a finite number of states. Every *cell* has the same rule for updating, based on the values in the *neighbourhood*. Each time the rules are applied to the whole grid a new *generation* is produced.

Therefore, the WCM acknowledges the existence of *collective agents*, a notion somewhat related to that of *swarms* in modelling, although in our case, our individuals follow and share a set of common rules, resources and information. The fundamental component that organizes the agents in a Swarm model is an object called a "swarm" (Minar et al. 1996). A swarm is a collection of agents with a schedule of events over those agents. For example, a swarm could be a collection of 10000 individuals, 10 communities, 3 river basins and 1 region, and a simple schedule: the individuals moving and consuming water, energy, and institutions exchanging information. The swarm represents an entire model: it contains the agents as well as the representation of time. In addition to being containers for agents, swarms can themselves be agents. A typical agent is modelled as a set of rules for responses to stimuli. But an agent can also itself be a swarm: a collection of objects and a schedule of actions. In this case, the agent's behaviour is defined by the emergent phenomena of the agents inside its swarm. Hierarchical models can be built by nesting multiple swarms (Figure 6).

[1] Note that all systems – living or otherwise – have 'structure'. The difference is that the structure of living systems is maintained using external energy by self-organising processes, that the structure is non-equilibrium and has to be maintained by the continuous use of an external energy source, that living systems have the capacity to repair and reproduce themselves using such energy and materials via 'metabolic processes' and that organisms are organized in relation to their environment and each other into closed material cycles.

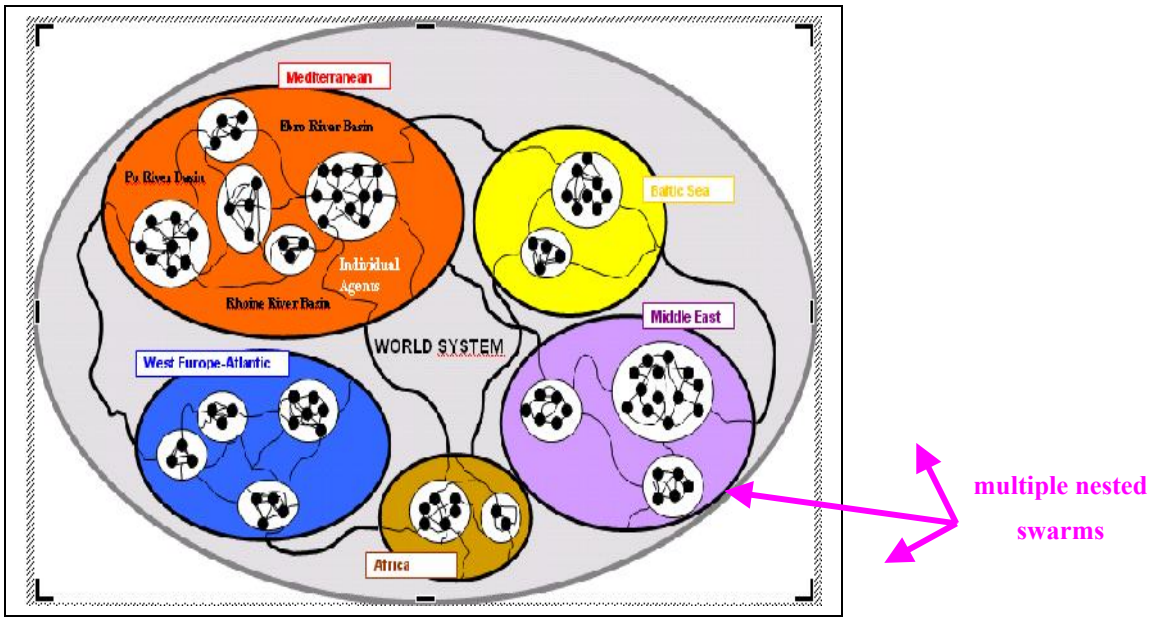


Figure 6. A simplified representation of the World Cellular model. An unsustainability situation can be represented whenever the 'size' of the agents surpasses the size of the system available to meet the agents' demands.

In current agent-based simulation environments the concept of swarm is still being used, although often they are no longer called swarms - instead now they are referred to simply as a set of models that are scheduled and interfaced together. Thus, in order to materialise our vision for the development of a new tool for the ISA of water management, we have opted for the development of a model which is able to represent:

- **Relationships between individual** agent-based behavioural changes **and** changes occurring at several scales, including **the World**, **understood as a total single system.**
- **Long-term time dynamics** (e.g. approximately up to 3 runs, each run comprising a decade, hence providing scenarios for 2030).
- **Land use changes**, with GIS.
- **Changes in the 'size'** of the agents, and socio-environmental regions and contexts of action as a result of changes in the use of resources (in our first prototype, only water and energy).
- Effects of **change in the speed** of the overall system, and the relationship of this overall systemic speed with the availability of (kinetic) energy and resources, acknowledging that different speeds of change occurs at different levels and parts of the system.
- Relationships between the scale of change and its **irreversibility.**
- **Effects of material and energy flows** on the evolution of different units of analysis -individuals, river basins, regions, World System; this also includes relationships between **energy availability and water consumption**.
- **Energy costs of environmental quality** of water and of the river basin (e.g. energy cost of resilience alteration).
- **Trade-offs and effects between** responses to persistent problems **and causes of new persistent problems at different scales.** In the case of water, there are evident trade-offs between short-term local positive effects on environmental water quality and long term global

negative effects on climate change (e.g. via GHG emissions from energy-intensive water treatment plants).

- **Main drivers of agents' water behaviour,** derived for instance, from information signals from the market system or change in rule systems.

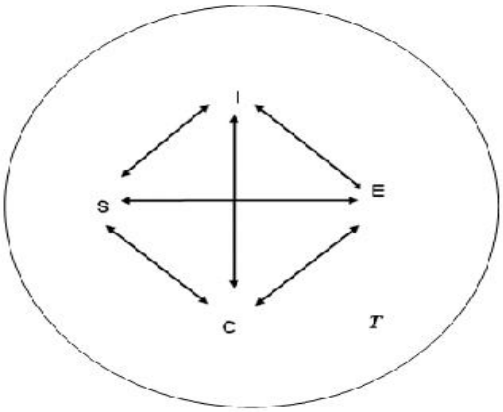
To illustrate type of change in mental, science and policy framing paradigm which is implied by this new way of looking at the relationships between human and natural systems in the domain of water, it may be worth briefly looking at how the current European Water Framework Directive (WFD) conceives water management within the European river basins (Kaika and Page 2003, Page and Kaika 2003, Carter & Hove, 2006). The European WFD talks of different 'water bodies', hence implicitly arguing that different types of waters exist –in a rather disconnected way between different river basins- and therefore need to be dealt differently. The WFD does not deal either with the ecological costs (e.g. in terms of energy consumption or climate change) of maintaining a 'good ecological' status of water or with issues such as individual behaviour and adaptation. Our approach aims to go beyond these conceptual limitations and propose an alternative approach. On the one hand, we assume that there is only one water system, in which water is mostly part of a total cycle of the larger World or 'body' system -which in turn can contain only one type of water, obviously of different qualities and states and performing different types of functions within the system[2]. Thus, we talk about one sole body of water, as the only one single type of water which exists within the World system that helps to sustain the diversity of life and human populations on Earth. On the other hand, we place special emphasis in identifiable agents and their behaviour as main drivers and recipients of change. Transitions in the water domain entail mostly changes in agents behaviours, or in other words an agent-based transition. This is why we have opted for the development of a cellular and organic model, using a double metaphor which perhaps best captures such complex but close interrelationships both at macro and micro levels (for a discussion of models in water policy see Hare, 2003, 2004, 2005, and for further explanation of the WC model, Tabara and Pahl-Wostl, 2006).

4. LINKING AGENTS' BEHAVIOURS TO SUSTAINABILITY SYSTEM CHANGE: A SYSTEMIC COADAPTIVE PERSPECTIVE

The WCM takes a 'total system' multi-scale agent perspective, in which each individual or collective agent responds to the availability and use of a set of stocks and flows of rules and/or institutions (S), energy and resources (E), information and knowledge (I), which in turn provokes system change (C) or impact on the whole social-ecological osystem. We refer to this as SEIC model (Tàbara, 2003) which derives from ecological sociology, and it is aimed at understanding agents' behaviour with regard to other agents as well as with regard to the rest of the system an interrelated, organic and coadaptive manner[3] (Figure 7).

[2] As noted by A Watts as early as in 1970 in his short essay the *World is your body*. To him, it is false to believe that 'the world is made up or composed of separate bits of things'. Hence, the analytical *distinction* is different from ontological *separation.*

[3] Social science and sociology in particular has been using concepts and models from natural sciences since their beginning. Herbert Spencer, for instance, in his *First Principles* (1862), was already looking for the conditions for stability, social differentiation and change of 'organic' social forms with the help of biological and Darwinian concepts and theories. In the twenties, the Human Ecology of the Chicago school also used an array of such concepts to understand the process occurring within the urban landscape. This line of thinking continued and generated important insights epitomised by figures such as Amos Hawley or Ottis Duncan. The latter produced a famous model in the late fifties, called P-O-E-T, aiming at understanding the interdependencies and dynamics between Population, Organisation, Environment and Technology. POET was the first attempt to provide an integrative approach to the social and environmental relationships, but ignored, as did the previous insight of the Human Ecology school, crucial aspects such as pollution stocks and dynamics and information systems. For the role of knowledge systems in sustainability see Cash, et al. 2003.



Where

S: Rules, institutional and social systems; social structure.

E: Energy, materials and natural resources

I : Information and knowledge

C: Socio-environmental systemic change or impact

Figure 7. The SEIC interpretative model.

The SEIC model should be understood not as a sustainability 'answering machine' but on the contrary, as a tool for reflection. It can be applied in a particular context of action with stakeholders to facilitate structured dialogue and stimulate questions as to initiate processes of *sustainability learning* –rather than give definite answers to existing regime questions. Among the questions that such structured dialogue can stimulate are the following: To which extent a particular institutional regime change (S) could contribute to a substantial reduction in the consumption of non-renewable energy and resources (E), to optimise the existing the knowledge base (I) and reduce of the systemic unwanted negative consequences on social-ecological systems (C)?[4] . In the case of water, such a question can be translated in the following: What type of institutional regimes and arrangements (S) are needed so that the present use of information and knowledge systems (I), such as market prices or IC tools, can be best used to deal with issues of increasing water and energy (E) and ecosystem pollution (C)?. Evidently, and due to the qualitative and complex nature of sustainability these are not questions which can easily answered at once and with one sole numeraire, but need an in-depth qualitative interpretation of the dynamics of each of the systems of reference taken into consideration.

Furthermore, and in order to explore the evolution of the behaviour of agents operating at different scales theWCM and the SEIC model can be linked as follows (Figure 8):

[4] Question which can be otherwise simplified by the following sustainability equation :How Sust **S** => f (↓**E**, **I**, ↓**C**)?

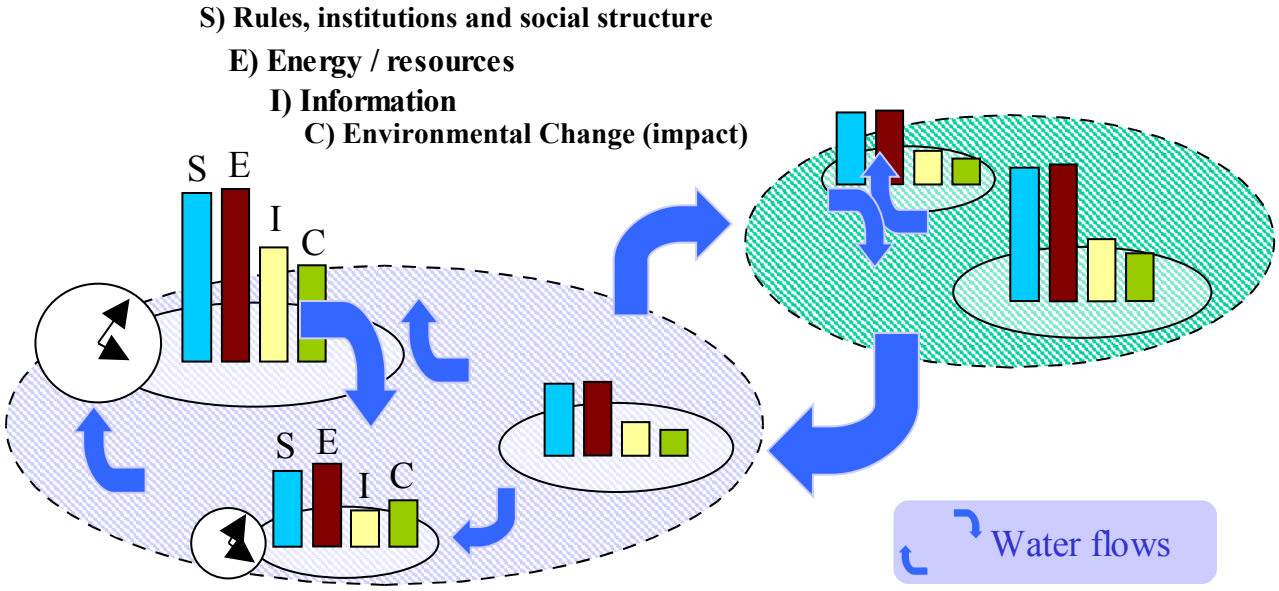


Figure 8. In the WCM agents' (cells) behaviours are explained by rules and institutions (S), the use of energy and resources (E), information and knowledge (I) and the impact such agents' behaviour provokes in a persistent and recursive way on the environment (C).

The width of the cell indicates the impact on the total amount water use caused by the agent (*water size* of the agent) and the width of the arrow indicates the size of the flows between agents resulting from their: 1) individual or institutional rules (S), 2) availability and regular use of energy (E) and materials, and by their 3) knowledge and information systems (I). Furthermore, the coevolutionary impact on agents' water use on the rest of the agents and the environmental impact on the whole water system is indicated by (C). This impact can simply be operationalised as the effects of the available water of other agents in the next period of interaction. An unsustainability trend can be represented when the total size of the agents moves towards a threshold which exceeds the size of the total system, in our case the world water system. However, the WC-SEIC tools is not intended to provide a single and definite definition of (un)sustainability which is valid for all contexts of reference, but only a general framework which can be use to define sustainability and it opposite unsustainability in the most social and ecological robust way so as to stimulate adaptive options for action.

5. COMPUTER SOFTWARE AND IMPLEMENTATION

Therefore our approach is that new methods and tools for ISA should be mostly be oriented towards *reflexive learning* and regime rather than prediction and forecasting plausible systems trends that reinforce existing regime paradigm. For this reason, we have placed the WC-SEIC model within a more general methodological framework which includes not only the social-ecological representation of the system via modelling but also a series of activities that can be used in a particular participatory setting to stimulate a knowledge rich and policy oriented discussion toward societal transformation. Figure 9 provides such approach.

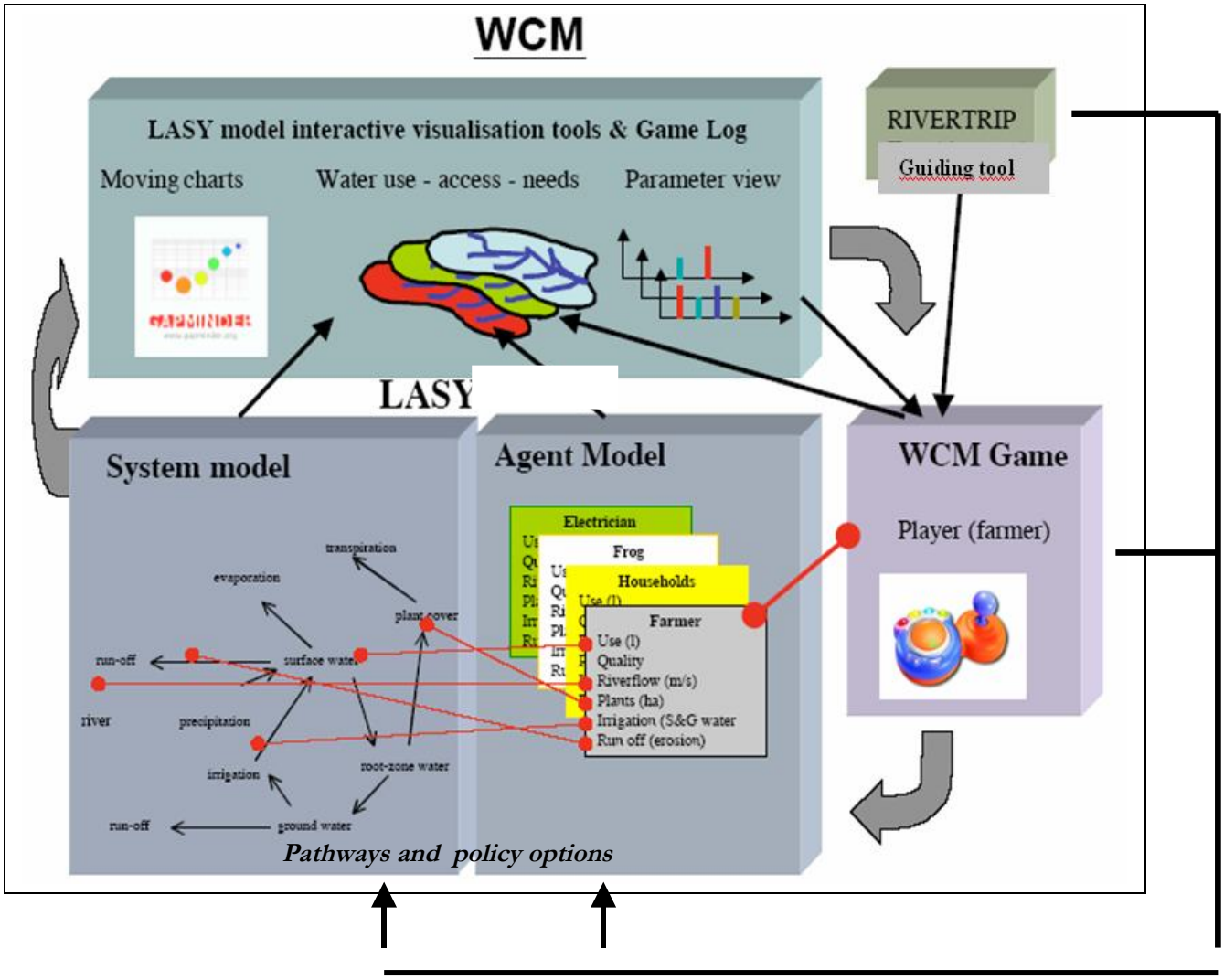


Figure 9. The World Cellular Participative Framework.

In particular, this framework, which at present stage concentrates only at a river basin scale, includes the following:

- A descriptive module with a series of data sets on river basin characteristics (water uses, needs and trends).
- A agent-based model, that represents main agents of the system of reference and its behaviours.
- A system model containing quantitative representation of biophysical dynamics.

- Two modules to enhance the social-ecological robustness of the WC approach and modelling interface:
  a) *A virtual river trip*: in which users of the WC framework can use to visualise both current and future states of the river depending to some baseline scenario or depending to particular development pathways and policy options. In this sense it is both a tool to illustrate how the future of the rive may look like if particular agent behaviour is extended to the rest of the system as to reflect upon what options are needed to prevent the future of the river basin look in a particular state.
  b) *A role game*: aimed at gaining insights of the drivers of system' agents behaviours and dynamics and to see to what extent the agents identified and selected by the model correspond to those which are relevant and influential in the system of reference.

We now turn to describe the model implementation in more detail.

5. 1. Modelling concept

To provide a first illustration the WCM was implemented with the generic software NetLogo (http://ccl.northwestern.edu/). This model described a river system consisting of two sub systems: the physical system describing the hydrology, and the agent system that describes the behaviour of the different agents. NetLogo has the capacity to combine agent-based modelling and system dynamics modelling in a spatially explicit environment. This makes it possible to explore the influence of the feedback mechanisms between the physical system and the agent system. The case of the Ebro river basin was used to explore the modelling concept.

However, the implementation of the model is now developed in AnyLogic (http://www.xjtek.com), a more powerful multi-paradigm modelling platform based on Java.

The physical model and its spatial representation

The physical model represents the stocks and flows of water in the river basin. The river basin is divided into uniform cells, currently 5 by 5 km, in a grid, see Figure 10, and each cell has its own characteristics that influence both the hydrology of the cell and the information conveyed to the agents, e.g. land use, erosion risks etc. This hydrological system is modelled using a system dynamics (SD) approach, see Figure11. In each grid cell this simple hydrological SD model is calculating the water balance in that particular cell. The input to each cell is water from the upstream cells and precipitation and the output is water flowing to the downstream cells and water use, including evapotranspiration.

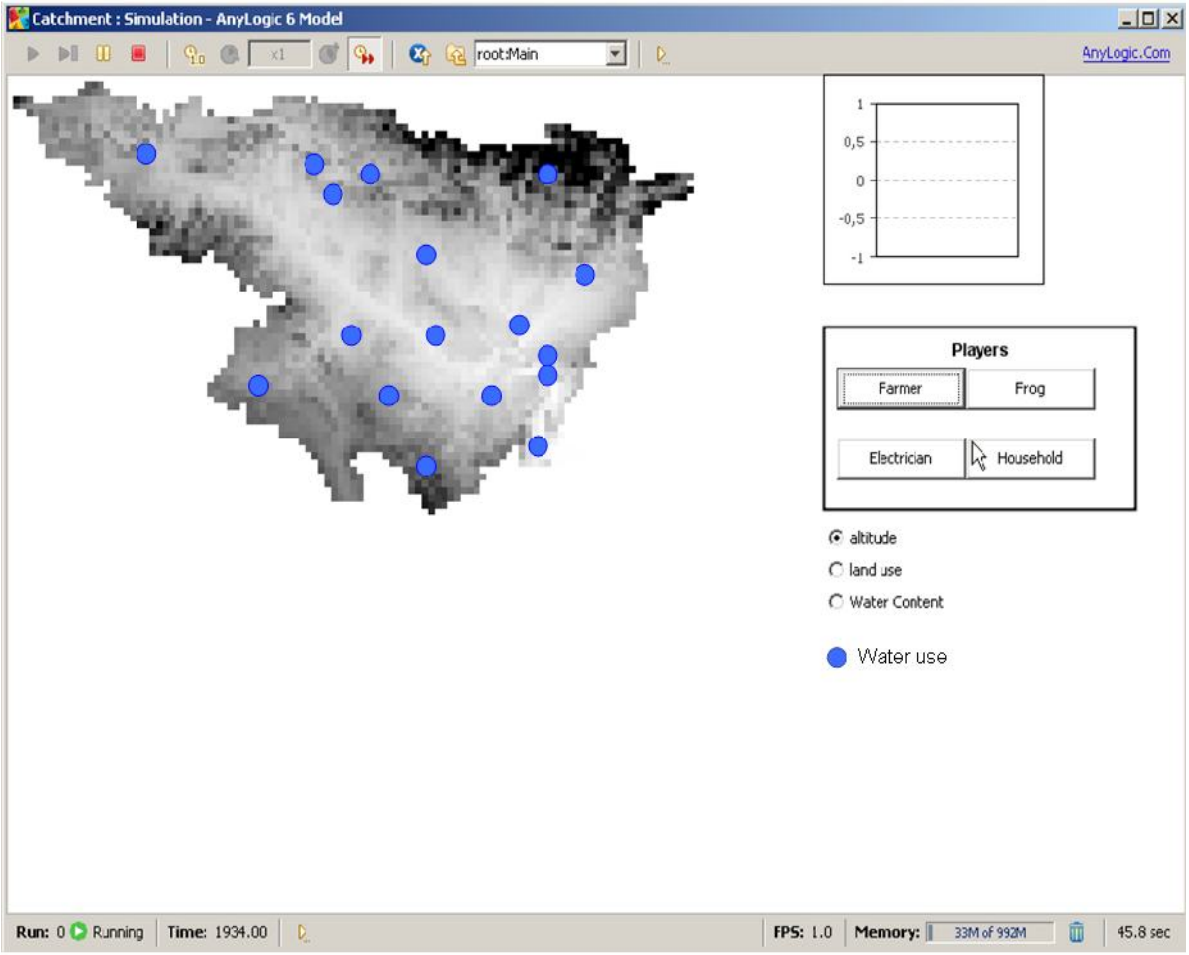


Figure 10. The Ebro River Basin in AnyLogic. Each square is 5 by 5 km.

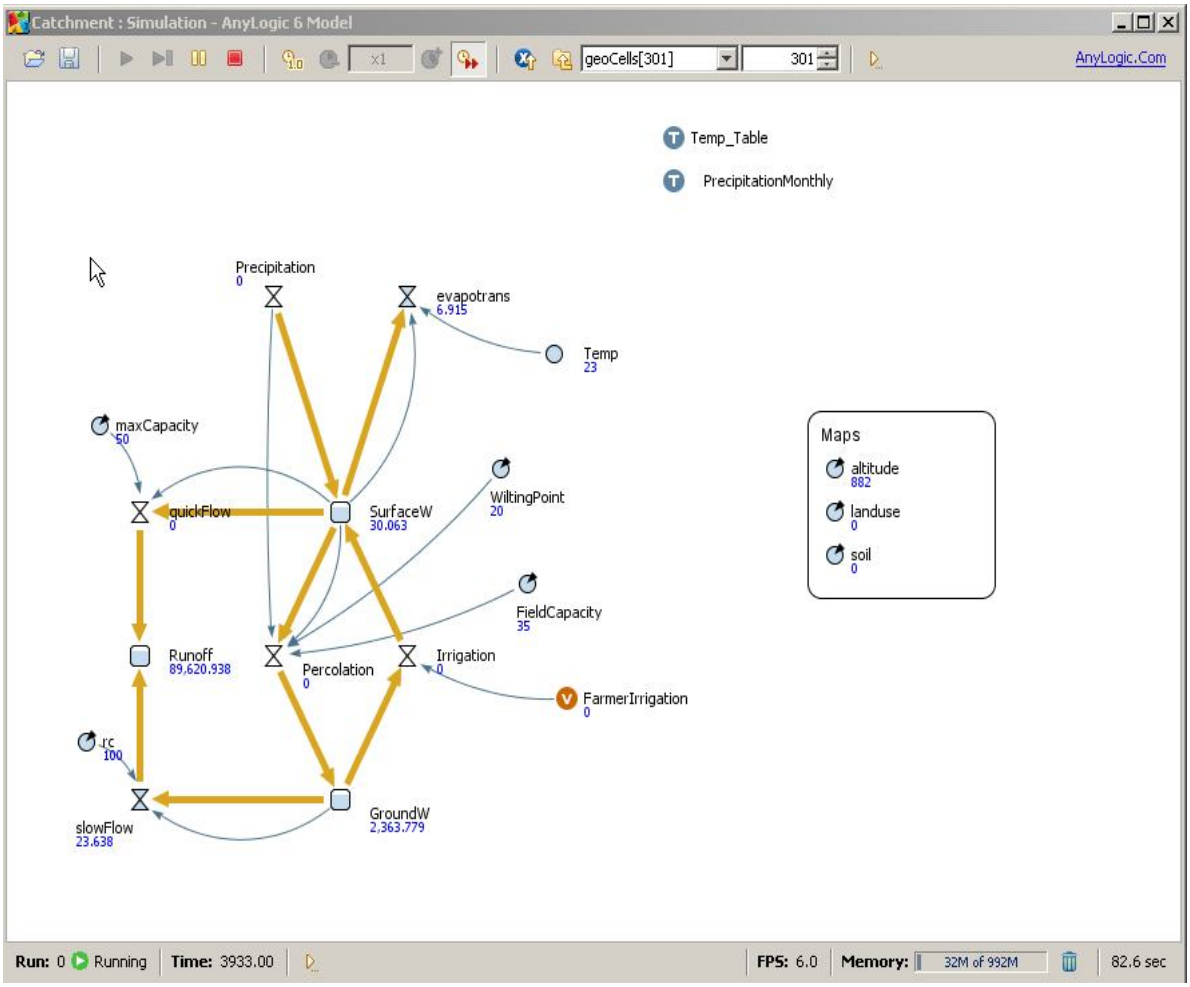


Figure 11. The SD model that calculates the water balance in each grid cell.

The agent model

The model is able to represent agents according to different criteria, e.g. related to economic factors, cultural factors, use of water, or power-related factors. In the first prototype, four types of agents are represented in the agent model: 1) farmers representing the agricultural water users, 2) electricians representing water dependent, but not water using humans that can make their voices heard, 3) frogs representing water dependent environmental values which cannot make their opinion heard by themselves and 4) households at this stage representing all human water consumption besides agriculture.

The agents can interact with and be influenced by their surroundings, the environment. They behave and make decisions depending on information that is provided not only by the hydrological SD model, but also other information about climate, climatic changes, land use etc. from the environment. The behaviour of and decisions made by the agents are in turn reflected in the physical model, see also Future development below.

Figure 7 illustrates the user interface in AnyLogic. The spatially aware agents are represented as circles of which the diameter reflects the current water use. The agents are given certain characteristics by the players, see Figure 12 and Figure 13.

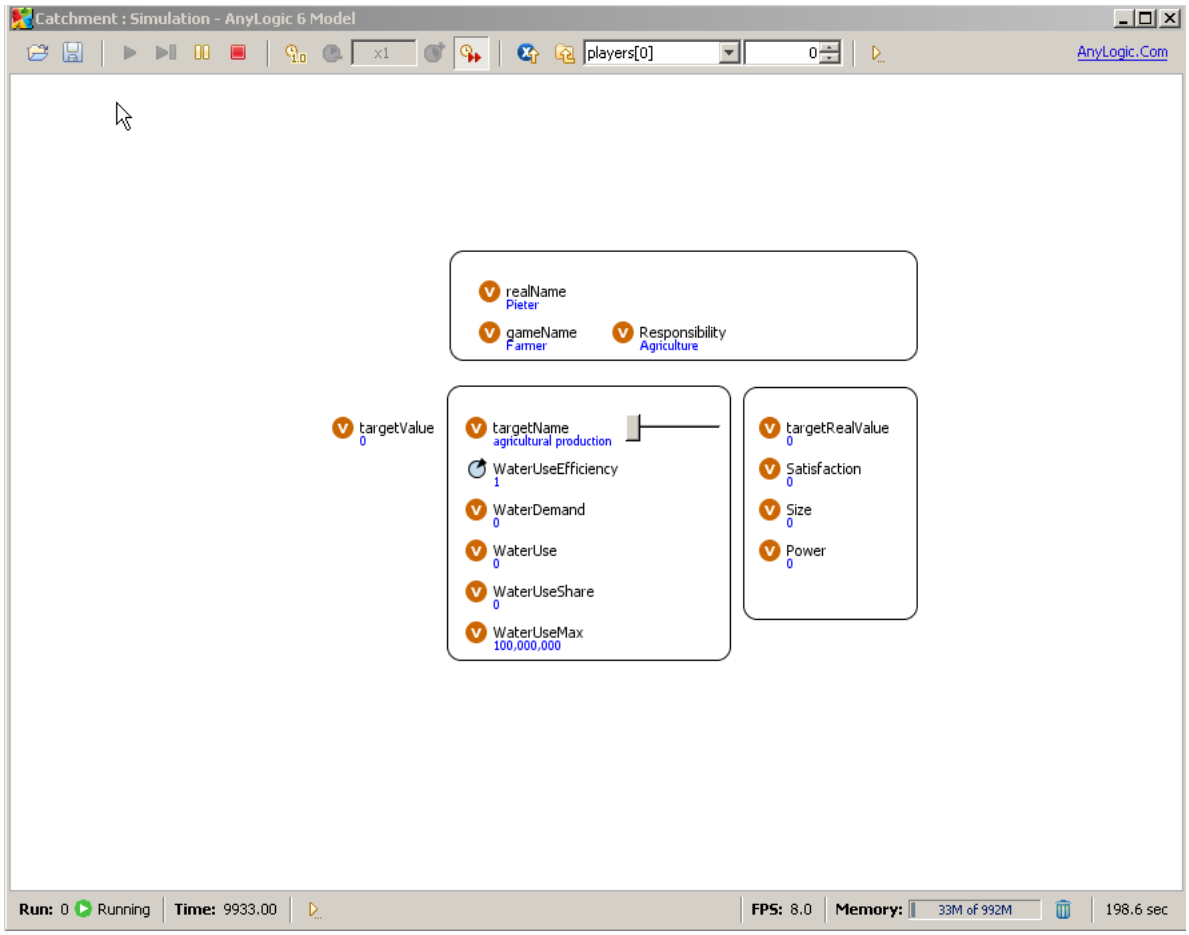


Figure 12.The characteristics of the agents can be easily modified in the user interface even on-the-fly during run-time.

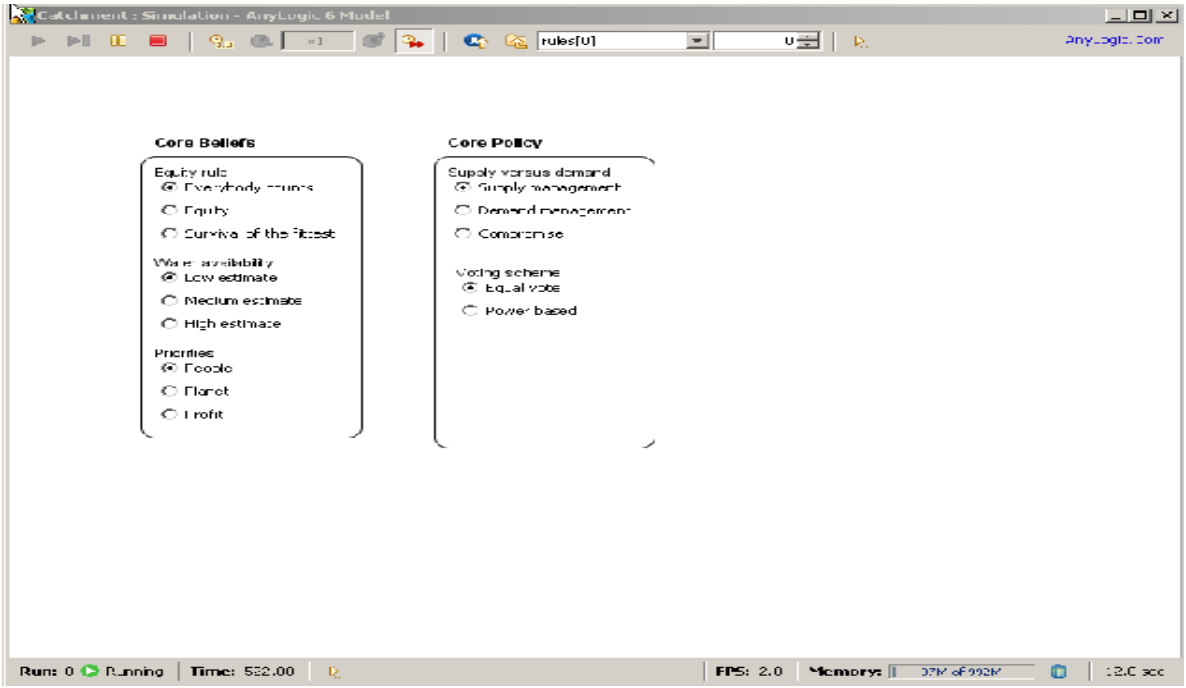


Figure 13. Core beliefs and policies is set by the player in the interface.

5.2. Future development

The WCM will be further developed using the AnyLogic software by:

- adding complexity in terms of agents' behaviour, size/speed of agents and system change, and the role of information, communication and conflict in the making of rules and regime changes;
- improving the interface for a better correspondence to the theoretical framework of the WCM;
- including a differentiated and dynamic representation of the water use by dividing the water use into different sectors, e.g. industry, agriculture and urban water use, which are dynamically linked (including feedback links) to the size of the industry, land use and population;
- including land use in the physical model. By analysing a land use map a grid map of lumped land use can be created with GIS. Within each grid the fraction of land used for a specific purpose is given, but the geographical location within the grid is not specified. Each land use type is assigned its own water use rate. This creates a 'semi-distributed' model in which the accuracy depends on the resolution of the chosen grid.
- A new version of AnyLogic (v. 6) supports interactive GIS maps which can be embedded into the AnyLogic 6 presentations and populated with graphic representations of the model objects, e.g. agents. The model, in turn, can use the GIS database to parameterize itself and also write the simulation output to the database. This will provide a very powerful way of modelling e.g. dynamic land use changes.

Agent-based modelling has proven useful in representing processes underlying particular phenomena, but it has a lower potential in spatial representation as available in GIS. GIS, on the other hand, has earlier mainly been used for the modelling of bio-physical interactions and has not, until recently , been used to incorporate human behavioural phenomena and object-oriented programming techniques. The integration of ABM, SD and GIS has a high potential as agent dynamics can be represented in three dimensions to illustrate and easily communicate the different relative agents' size and the dynamics of a common resource and the environmental space. The agent base representation can be linked to a GIS map, such as those provided by the Ebro Water authority on the size of cities, according to their population (CHE, 2005)[5]. The very important feedbacks between the different modelled sub systems can also be taken into account with this approach.

Last but now least, it should be noted that the main innovative idea comes from the whole WCM framework, and the application of ABM, SD, GIS, and a learning tool used in a participatory context, not solely from the model as a stand-alone software.

6. FINAL REMARKS

Unsustainability persistent problems are relational problems, so the 'solutions' –that is, the measures or policies to be implemented, as there are no solution to them in the traditional sense- to these problems must also be of a relational nature. Sustainability problems are not problems occurring 'out there', independently from our individual, collective and daily multi-scale behaviours. Hence, Integrated Sustainability Assessment of policy programs needs to provide knowledge on how to provide alternative visions and paradigms able to change in a structural / persistent way the

[5] In this respect an important further development of this model will be to link such agent-based model with the modelling of land use and land cover change. Understanding of the driving forces of land use and land cover change has improved and is now characterised by complexity and a deeper knowledge of the variability in time and space . For example poverty and population are no longer seen as the sole and major underlying global land use and land cover change . Newer approaches combine elements of different modelling techniques and the trend is going towards integrated models with increasing size and complexity such as IMAGE .

relationships between the natural and social systems at the individual, meso and the macro level. The first step is to identify such relationships in an operational and meaningful e way so that it can be communicated and used by the relevant agents who drive the system.

In order to do so, a new way of framing policy options and futures, as well as new tools and methods to do so is needed. Our approach, based on a conceptual SEIC-WC model is being used to understand agents' behaviour with regard to the use of natural resources. This new conceptual framework and the suggested participatory interface that is being designed with it may help to create a valid and relevant ISA narratives capable of supporting social and institutional learning within the water domain. We argue that new ISA methods and tools should not only focus on the isolated analysis of *impacts* of policy options, but mostly on systemic social-ecological interrelationships. This should *include not only impacts but also interdependencies and influences between agents and its* cumulative consequences (e.g. loss of sustainability stocks) on both natural and social systems. From a systemic perspective, impacts of policy options are both effects and causes of future environmental changes, which will constrain or enhance next sustainability options for development.

However, in this paper we only focused in showing part of the ongoing work which relates to the development of a new modelling tool and framework aimed at supporting processes of Integrated Sustainability Assessment of water resources. The applications shown in this paper are therefore only a relative small part of a much larger research effort which include also the domains of land-use and agriculture, new technologies (hydrogen) and dematerialization. Furthermore, the results shown in this paper are likely to rapidly evolve as we get more insights into the individual and collective agents' behaviour, their impacts on their life support systems, and in turn, on the consequences of such changes on the agents' adaptive behaviour.

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REFERENCES

Alcamo, J. (1998) Global change scenarios of the 21st Century: results from the image 2.1 model, Oxford, Pergamon.

Boulding, K. (1985). The world as a total system. Beverly Hills, CA: Sage.

Carter, J. and J. Howe 2006. The Water Framework Directive and the Strategic Environmental Assessment Directive: Exploring the linkages. Environmental Impact Assessment 26:287-300.

Cash, D. W., C. W. Clark, F. Alcock, N. M. Dickson, N. Eckley, D. H. Guston, & J. Jäger. 2003. 'Knowledge systems for sustainable development'. Proceedings of the National Academy of Sciences, 100:8086-8091.

Confederación Hidrográfica del Ebro (CHE). 2005 Informe, 2005. Caracterización de la Demarcación y Registro de Zonas Protegidas (Borrador provisional de 31 de marzo. Directiva Marco del Agua, Demarcacion Hidrografica del Ebro, 2005. Ministerio de Medioambiente, Confederacion Hidrografica del Ebro (CHE). http://oph.chebro.es/DOCUMENTACION/DirectivaMarco/DemarcacionDirectivaM.htm

Guerin (a) Redfish group. Peeking into the Black Box: Some Art and Science to Visualizing Agent-Based Models http://www.redfish.com/research/PeekingIntoTheBlackBox.pdf

Guerin (a) Redfish group. Reality Mining: Group Behavior. http://reality.media.mit.edu/groupviz.php

Gimblett, H. R. (2002) *Integrating geographic information systems and agent-based modeling techniques for simulating social and ecological processes,* New York ; Oxford, Oxford University Press

Hare, M. (2005). The use of Models to Support the Participatory Elements of the EU Water Framework Directive: Creating a Dialogye between Policy Makers and Model Makers. HarmoniCA document: Seecon Deutschland GmbH & Osnabrük University. http://www.harmoni-ca.info

Hare, M. (2004). Modellers recommended Research Directions for Models to Support the Participatory Elements of the Water Framework Directive. http://www.harmoni-ca.info

Hare, M. (2003). Policy Makers' Requirements for Models to Support the Participatory Elements of the Water Framework Directive. HarmoniCA document. Seecon Deutschland GmbH & Osnabrük University. http://www.harmoni-ca.info

Hare, M. & Deadman, P. (2004) Further towards a taxonomy of agent-based simulation models in environmental management. *Mathematics and Computers in Simulation,* 64**,** 25-40

Hoekstra, A. Y., Beusen, A. H. W., Hilderink, H. B. M. & Van Asselt, M. B. A. (1997) Water in crisis? IN Rotmans, J. & De Vries, B. (Eds.) Perspectives on global change: the TARGET approach. Cambridge, Cambridge University Press.

Kaika, M. and B. Page 2003. 'The EU Water Framework Directive. Part 1. European Policy Making and the Changing Topography of Lobbying'. European Environment, 13: 314-327.

Kasemir, B.; Jäger, J. Jaeger, C. Gardner, M.T. (Eds). (2003). Public Participation in Sustainability Science. A Handbook. Cambridge: Cambridge University Press.

Lambin, E. F., Geist, H. J. & Lepers, E. (2003) Dynamics of Land-Use and Land-Cover Change in Tropical Regions. Annual Review of Environment and Resources, 28**,** 205-41

Lambin, E. F., Rounsevell, M. D. A. & Geist, H. J. (2000) Are agricultural land-use models able to predict changes in land-use intensity? Agriculture, Ecosystems and Environment, 82**,** 321.

Lambin, E. F., Turner, B. L., Geist, H. J., Agbola, S. B., Angelsen, A., Bruce, J. W., Coomes, O. T., Dirzo, R., Fischer, G., Folke, C., George, P.S., Homewood, K., Imbernon, J., Leemans, R., Li,

X., Moran, E. F., Mortimore, M., Ramakrishnan, P. S., Richards, J. F., Skanes, H., Steffen, W., Stone, G. D., Svedin, U., Veldkamp, T. A., Vogel, C. & Xu, J. (2001) The causes of land-use and land-cover change: moving beyond the myths. Global Environmental Change, 11, 261-269.

Meadows, D. H. , Meadows, D. L. , Randers, and W. W. Behrens. (1972). The Limits to Growth. New York. Universe.

Miller, J. G. and Jessie L. Miller. (1978). The Earth as a System. University of California at Santa Barbara. http://www.isss.org/primer/earthsys.htm

Minar, Nelson et al. (1996). The Swarm Simulation System: A Toolkit for Building Multi-agent Simulations. http://www.swarm.org/images/b/bb/MinarEtAl96.pdf

Mulino Project, Mulino-DSS Demo. http://siti.feem.it/mulino/

Page, B. & M. Kaika 2003. The EU Water Framework Directive. Part 2. Policy Innovation and the Shifting Choreography of Governance. European Environment, 13:328-343.

Robinson, J. B. (1991). 'Modelling the interactions between human and natural systems'. International Social SciencE Journal, 130:629-648.

Tàbara, D. (2006 (2003)). 'Participatory Sustainability Assessment using computer models'. In P. Valkering et al. More puzzle Solving For Policy. Integrated Assessment from Theory to Practice. The Netherlands: International Institute of Integrative Studies - European Forum for Integrated Environmental Assessment. Maastrich: ICIS. http://www.icis.unimaas.nl/downloads/SummerCourseBook_051201.pd

Tàbara, (2005). Nothing is outside the system. But what is the system? A systems learning reflection on the type of knowledge expected from ISA and Matisse case studies. In: P. Weaver, J. Tàbara, J. Rotmans, A. Haxeltine, J. Jaeger. Sustainability: a systemic synthesis from the perspective of Integrated Sustainability Assessment. Deliverable D1.1. Matisse project.

Tàbara, D. (2003). 'Teoría Socioambiental y sociología ecológica'. (Socioenvironmental Theory and Ecological Sociology). Published in S. Giner, Teoría Sociológica Moderna. Madrid: Ariel. p.431-458.

Tàbara, D. & C. Pahl-Wostl (2007). Sustainability learning in the management of social-ecological systems. WP6. Matisse Working Paper.

Tàbara, D. et al. (2006a). 'Stakeholder and Socioenvironmental Analysis for the Integrated Sustainability Assessment (ISA) Of The Ebro River Basin' Deliverable D2.6.

Tàbara, D. (2006b). 'A Comprehensive analysis of tools and methods for integrated sustainability assessment of water using common generic principles. Applying ISA methodology and creating new sustainability narratives with the World Cellular and the SEIC models in the Ebro River basin'. Matisse project Deliverable D2.6.

Van Asselt, M. B. A. & Rotmans, J. (1997) Uncertanties in perspective. IN Rotmans, J. & De Vries, B. (Eds.) Perspectives on global change: the TARGETS approach.

Watts, A. 1970. 'The world is your body'. In R. Disch (1970). The Ecological Conscience. Values for Survival. New Jersey, Prentice-Hall.

Weaver, P.M. and J. Rotmans (2006). Integrated Sustainability Assessment: what is it, why do it, and how?, International Journal of Innovation and Sustainable Development. Vol. 1, No.4

Wieringa, H. & J. P. van Soest 1985. 'De Nederlandse landboouw op een keerpunt?', Landdbourwkundig Tijdschrift, 97 (11): 5-9. Extract translated and cited in Jan van Mansvelt 'The frole of lower-input technologies in the future' in M. Whitby & J. Ollerenshaw (1987) Land Use and the European Environment. London: Belhaven Press, pp. 42 -53

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