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Re-opening the black box in Societal Metabolism: the application of MuSIASEM to water

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ABSTRACT

In this paper we address the complexity of the analysis of water use in relation to the issue of sustainability. In fact, the flows of water in our planet represent a complex reality which can be studied using many different perceptions and narratives referring to different scales and dimensions of analysis. For this reason, a quantitative analysis of water use has to be based on analytical methods that are semantically open: they must be able to define what we mean with the term “water” when crossing different scales of analysis. We propose here a definition of water as a resource that deal with the many services it provides to humans and ecosystems. We argue that water can fulfil so many of them since the element has many characteristics that allow for the resource to be labelled with different attributes, depending on the end use –such as drinkable. Since the services for humans and the functions for ecosystems associated with water flows are defined on different scales but still interconnected it is necessary to organize our assessment of water use across different hierarchical levels. In order to do so we define how to approach the study of water use in the Societal Metabolism, by proposing the Water Metabolism, organized in three levels: societal level, ecosystem level and global level. The possible end uses we distinguish for the society are: personal/physiological use, household use, economic use. Organizing the study of “water use” across all these levels increases the usefulness of the quantitative analysis and the possibilities of finding relevant and comparable results. To achieve this result, we adapted a method developed to deal with multi-level, multi-scale analysis - the Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism (MuSIASEM) approach - to the analysis of water metabolism. In this paper, we discuss the peculiar analytical identity that “water” shows within multi-scale metabolic studies: water represents a flow-element when considering the metabolism of social systems (at a small scale, when describing the water metabolism inside the society) and a fund-element when considering the metabolism o ecosystems (at a larger scale when describing the water metabolism outside the society). The theoretical analysis is illustrated using two case studies which characterize the metabolic patterns regarding water use of a productive system in Catalonia and a water management policy in Andarax River Basin in Andalusia.

Keywords: Andalusia, Catalonia, Flow/Fund Model, MuSIASEM, Water, Water Metabolism.

JEL Keywords: Q25-Water; Q56-Environmental Accounting; Q57-Bioeconomics&Ecological Economics; R19-Regional Economics/Other; R34-Input Demand Analysis.

Part I: Inserting Water in the Multi-Scale Integrated Analysis of Societal and Environmental Metabolism

1. Introduction

Water is one of the most important resources for human life yet one of the most unknown and ignored topic in the field of integrated assessment. When dealing with the analysis of shortage of resources, scientific research has traditionally focussed on energy, minerals or biomass uses with a relative marginalization of water. There are several reasons for this asymmetry: (1) the differences of the volumes of water use regarding the use of other materials (thousand times more), which make water become an unbalancing factor (Matthews et al., 2000); (2) the lack of reliable statistical data on water use; and (3) the intrinsic difficulty in dealing with the issue of scale (e.g. many conceptualizations of water resources are incompatible with the adoption of conventional geographic scales) makes it difficult to study water flows. As a result, when the use of water is studied, the available methodologies are in general not able to cope with the complexity of such a task. The approaches to the analysis of water use can go from: (i) local study of physical flows; (ii) combination of physical flows with monetary flows; (iii) analysis of the relation between physical and economic flows and their contextualization; (iv) the definition and analysis of metabolic patterns across scales.

This last option requires a “semantically open quantitative approach” that allows the adoption of multiple perspectives – i.e. non-equivalent representations associated with different scales. In the case of water, this means that the method we chose for the analysis should be able of qualifying in different ways the volumes of water to be analyzed. We argue that this method – the definition and analysis of metabolic patterns using a multi-scale integrated characterization - is the most comprehensive approach and possibly the only one able to include in the analysis of water use the especial characteristics of water which make it a unique element.

From the approaches previously mentioned, several methodologies have been developed to perform water use analysis mainly by accounting and assessing flows in relation to the study of the concept of Virtual Water[1] (Allan, 1998). This approach gives to water the dimension of a geopolitical factor. In doing so, the concept includes a qualitative aspect of water. However existing methods of quantification of Virtual Water “flows” do not address explicitly this qualitative aspect. As a matter of fact, available works are mainly related to the quantitative estimation of water flows and sometimes its relation to associated monetary flows at one geographical scale. Studies of this type refer to global (Hoekstra and Hung, 2005; Chapagain et al., 2006; Chapagain and Hoekstra, 2008; Mekonnen and Hoekstra, 2010) or regional levels (Madrid and Velázquez, 2008; Bulsink et al., 2010; Zeitoun et al., 2010). Attempts to include beside the quantitative aspect also qualitative characteristics of water have also been done by estimating indicators on blue and green water use

[1] Defined as the amount of water used to produce a good or service.

–depending on the source of the water- and grey water –to indicate that is later on polluted (Aldaya et al., 2009, 2010; Chapagain and Hoekstra, 2011). Regarding the relation with the economic system, Input-Output methods have been implemented to assess the potential economic value of water used by different subsystems – economic sectors - including direct and indirect use as well as virtual water flows (Duarte et al., 2002; Huang et al., 2005; Velázquez, 2006; Dietzenbacher and Stage, 2006; Dietzenbacher and Velázquez, 2007; Guan and Hubacek, 2007, 2008; Llop, 2008; Zhao et al., 2009, 2010; Blackhurst et al., 2010; Cazcarro et al., 2010; Aviso et al., 2011).

The choice and development of a methodology for water use analysis entails the difficulty that usually there are not methodologies specifically created to analyze water use, but some others are adapted to this end. The issue in this case is that not all the methodologies can be adapted to water complexity mainly because of two reasons. First, the qualities –that we will later call relevant attributes- considered to characterize usable water depend on an integrated valuation of the characteristics of the element water which positive science is not used to develop. Second, even when the integrated valuation is done and water is qualified, it is difficult that this information remains valid when any of the original characteristics changes. These two systemic difficulties are clearly illustrated by the fact that we do not have a well established and universally accepted methodology which is commonly adopted for assessing water use. The definition of "what water is" and "how to quantify water use" is probably the most important source of epistemological troubles in this field. In fact, the pre-analytical narrative chosen by the analyst to define "what is water" does affect the quantitative results of the assessment (and in cascade the choice of a desirable policy). Put it in another way, different understandings – i.e. perceptions and representations - of the "element water" will lead to the adoption of different assessing methodologies, different quantitative results and therefore to diverse policies of water governance.

In this paper we argue in general terms that an analysis of "water use" has to be carried out on the interface society/ecosystem, in order to be able to look at both internal implications (how water is used inside the society for guaranteeing relevant societal functions) and external implications (how water uses affect the stability of ecological processes operating within the water cycle defined at a larger scale). The internal analysis is required to provide the set of relevant attributes to be used to characterize the usefulness of "water" in relation to human uses (for an analysis of what are called internal constraints of the metabolic pattern). The external analysis is required to provide the set of relevant attributes to be used to characterize the availability of "water" in relation to ecological processes (for an analysis of what are called external constraints of the metabolic pattern). Since water represents an important asset for humans - stabilizing and reproducing the socio-economic process - and at the same time represents a key element guaranteeing the stability and reproduction of ecological processes, we propose to use the conceptualization of "water" in relation to the services delivered to society, as provided by Aguilera Klink (1995): water should be considered as an Ecosocial Asset.

From this perspective, an analysis of water use must be beyond a simple flow analysis - focusing on the requirement of a given input of water for a specific process at a given local scale - and become a multi-scale integrated assessment carried out within a more complex approach. We can give two reasons to justify this claim. In first place, there is no other physical resource, which provides so many services for both humans and ecosystems. Water is a fundamental and irreplaceable element for both economic and ecological processes. And second, social dynamics are interacting with ecosystem dynamics, which in turn are interacting with the global Water Cycle.

These three different dynamics and their relative interaction can only be described by using different scales.

The Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism (MuSIASEM) is a framework that allows an integrated analysis of: (i) the social characteristics associated with resource use described, across different hierarchical levels, as generating the metabolic patterns[2] of a society; and (ii) the characteristics of ecological processes associated with the availability of sources of water for society, described across different hierarchical levels of analysis. This method has been developed for the study of other resource uses such energy and materials; therefore it requires a few adjustments before being applied to study of water use. In spite of that the advantage of MuSIASEM is that it makes it possible to generate an analysis across levels (subsystems of society) using a semantically open definition of the systems and the resources under assessment. Once this method of accounting is chosen, it is now necessary to discuss how to properly define “water” and “water use” before being able to implement it.

In the rest of the paper, we first propose a grammar (a definition of an expected set of relations over a set of semantic and formal categories associated with production rules) which can be used for a quantitative analysis of Water Metabolism, based on the MuSIASEM rationale. Then we test the usefulness of this grammar in two case studies. As a consequence of this, the paper is structured in two parts. In part one, we discuss the issue of how to define “water” in order to properly incorporate its uniqueness in the MuSIASEM approach. This section starts with an analysis of the characteristics and the services and functions of water that are essential for the maintenance of ecological and social systems in section 2. Then, we propose an approach to the assessment of Water Metabolism based on the Flow/Fund model proposed by Georgescu-Roegen, which is at the basis of the MuSIASEM. We introduce the analytical framework of the MuSIASEM method in section 3. In part two, we provide examples of quantitative applications in order to illustrate the potentialities of the MuSIASEM framework to the analysis of water use to assess both production patterns (section 4) and water policies (section 5). Finally there is a section of conclusion (section 6) wrapping-up the discussions presented in both parts.

2. Water Metabolism

The use of the concept of metabolism in social sciences comes from the original concept of metabolism in Biology. We need to recover this description in order to proceed with our analysis. In one of the better known books on Cell Biology, (Alberts et al., 2007) is argued that the metabolism of the cell is formed by “two opposing streams of chemical reactions”: Anabolism (the forming of molecules using energy and material to construct) and Catabolism (the breaking of molecules to get energy and material). In their physiological metabolic pattern, cells can defy the second law of thermodynamics (the entropy law) and maintain internal order because of the peculiarity of the metabolic process: (i) the metabolic process is taking place in open systems -that is, *cells are not isolated* so they can transfer their entropy increase to the surroundings- and (ii) there is a multiscale organization of the cell which makes it possible to establish a metabolic

[2] That is, the profile of use or consumption of relevant resources.

pattern. A metabolic pattern is therefore a local process which generates a property of the system at a larger scale, that is, the combination of the metabolic patterns of the subsystems allows the definition of the system.

Also the social metabolism can be divided into two types of coupled processes – anabolism and catabolism. And as well the socio-economic systems can defy the entropy law. On one hand, because societies are open systems embedded in a context, with which they can exchange matter and energy. On the other, since societies are composed by parts whose activities at one level express functions at higher levels which maintain the "order" of the society (its identity). The metabolism of societies is a multiscale and autopoietic process which requires, to be studied, a complex approach no longer based on the simplifications of reductionism.

The study of the Societal Metabolism as a way of analysing the biophysical needs of the societies has acquired relevance in the last ten years, mainly as a consequence of the energetic crisis. The quick spread of the concept among different fields of science is the responsible of the lack of a commonly accepted definition of it. Good reviews of the use of the concept in different fields and sciences are already published (Martinez-Alier and Schlüpmann, 1987; Fischer-Kowalski, 1998; Swyngedouw, 2006; Giampietro and Mayumi, 2009; Giampietro et al., 2011). The diversity of takes on these concepts has derived in a number of methodologies of assessment of resource use. All these methodologies, which we mentioned before, are certainly providing useful insights for understanding the relation between water use and the process of maintenance and reproduction of societal systems which use it.

For the purpose of analyzing water use, we consider the implementation of the concept of societal metabolism based on the flow-fund model of Georgescu-Roegen (1971) to be the most useful since it incorporates the idea of Metabolic Flow and Fund. In the Flow/Fund model of Georgescu Roegen (GR), flows and funds are the two categories of production factors acting in the economic process. Since the Flow and Fund concepts are "*designed to analyze qualitative change occurring within a production process"* (Farrell and Mayumi, 2009), this frame allows us to handle the special characteristics of water, when perceived and described simultaneously across different scales, as we will discuss below. The Flow/Fund model is different from the Flow/Stock model under which the most of the water use analyses mentioned before are carried out. The difference between these two models is that the Flow/Stock uses for biophysical analysis a simpler distinction. Here, a flow refers to a quantity of something that disappears during the analysis, whereas a stock refers to something that "remains" during the analysis. However, this generic distinction does not specify whether the identity of the stock changes during the analysis or not, as it would do if there is degradation in the quality of the stock.

We prefer the Flow/Fund model because of various reasons. In first place it offers the possibility of providing a more useful picture of the biophysical system under analysis by making possible to create a distinction between Fund-elements (not consumed) and Stock-elements (consumed). In second place, the definition of water as a fund element makes it possible to address qualitative aspects very relevant when analyzing water metabolism, as we will see. Third, it escapes the inertia of locomotion when speaking about accumulation and decumulation. In fact, in order to characterize water as a fund element, the temporal scale is essential for the suitable identification of the elements as flows and funds. The differentiation between flows and funds allows us to identify within different perspectives – e.g within the society or the ecosystems – "what the system is" (fund elements) and "what the systems does" (flows elements) and therefore helps us answer not only the question about what is used by the system (water) but also the question about how the system is using it and why. In fact, this model allows us to understand not only the essence of the resource the system uses, but also the nature of the system itself.

In this way of understanding societal metabolism, three sets of key questions are addressed: i) the question about how water is understood (identification of useful perceptions); ii) the question about how to define the water-using system (identification of pertinent representations); and iii) the explanations of how and why the system is using water. The "How the system uses water" question can be answered by analyzing the amounts and qualities of water used in social subsystems and at different scales. The "Why the system uses water" question is clarified by the identification of the relevant subsystems which use the water to express expected functions. Since the two first sets of questions "How do we understand water" (what are the useful perceptions of "water" to be used in the definition of the issues to analyze) and the "How do we define the water-using system" (what are the pertinent representations to be used in the quantitative characterization) depend on the purpose of the analysis we want to develop, the method of analysis has to remain semantically open, that is to say that it should allow for different answers to these questions. This openness means that boundaries and variables for the analysis can be defined in a flexible way in order to be able to handle better the complexity hidden behind the characterization of resource uses regarding the specific goals of different studies carried out in different contexts. What we do in this work, is to identify the parts to be used in the analysis of water use that can be common for all analysis, that is, the idea that water is a resource because it has unique characteristics which provide services to humans and ecosystems and the idea that water qualitative analysis can be done by taking into account its multiple roles as a flow or as a fund.

2.1. The impredicative concept of "water resource"

The element "water" exists in everyone's reality but in order to be incorporated in an analysis the analyst must first "conceptualize" it, that is, define an useful perception required to give it an analytical definition. Therefore, the question about how to define water is strictly speaking a question about how we perceive water. This perception -and the consequent definition- will depend on the narrative we adopt. That is to say, the perspective we have. Examples of narratives are scientific disciplines -as Physics, Geography, Anthropology or Economics- or cultures –as occidental vs. oriental perspectives- or combinations of both –occidental vs oriental Medicine. Every narrative has a range of "descriptive domains" which can be used to give water the necessary analytical definition. A descriptive domain is the reference scale chosen within each narrative to look at the element "water" in terms of relevant attributes in order to make a quantitative representation. For the Nuclear Chemist using an electronic microscope, water will be a set of atoms with certain properties. For Economists, using data about water consumption, water has been traditionally a productive factor. For Hindus, looking at the Ganga River with their own eye, water is the mother element, essential for life. But if we accept that "water" is all these perceptions at the same time then we have also to accept that the analysis of "water use" cannot be made without taking this fact into account.

We could aggregate all the previous ideas by saying that water can be considered a "resource". There are three ideas provided by three milestones in social sciences which are interesting for our definition of water as a resource here. Institutional economist and geographer Erich W. Zimmermann developed a well-known resource theory, (Zimmermann et al., 1933; Zimmermann, 1951) which has been summarized in the slogan 'resources are not, they become'[3]. This definition stresses the fact that an element is classified as a resource only when it provides any service to humans. Zimmermann's contribution to resource theory is important for its variety of interpretations as well as for the novelty of the definition of resource as something else than a productive factor, i.e. something that is related to human needs. From this theory, we keep the idea that a resource provides a benefit to a given end, in this case a human end.

Second, Geographer Tony Allan qualified water as "Multi-functional". By this term, Allan refers to the fact that water can be "used in different sectors and within these sectors it can be used for different purposes and for different functions" (Allan, 2001). Therefore water is not only a resource just for one end, but for many. Finally, Institutional Economist Federico Aguilera Klink added a less anthropocentric perspective when he defines it as an "Ecosocial Asset" (Aguilera Klink, 1995). With this idea, the author depicts water as an economic, ecological and social asset since it provides many benefits for ecological, economic and social systems. That is to say, water is a resource for many ends and not only for humans, since it provides benefits for other systems as well. Therefore, our "water resource" is an Ecosocial Asset, which is able to provide benefits to many ends for many systems.

That water can be a resource for many ends does not mean that a certain amount of water is necessarily suitable for all the ends nor that can be used for many purposes at the same time. Normally, we use a certain amount of water at a time for one purpose in one process. In each process, we are using the water resource in a different way. Therefore water is like a different resource for different processes, since it provides different benefits to different ends. This versatility is a consequence of the fact that water is a special element with many characteristics interesting for different systems. We can identify the following relevant characteristics of the element water: quantity, purity, pH, temperature, temporal and geographical reference or cultural meaning. Different combinations of the values of these characteristics provide water with different attributes. An attribute is a specific property of a given observed entity. Examples of attributes of the water resource would be "Drinkable", "Navigable" or "Potential-Energy Filled".

The condition of resource is based on a set of attributes which must be finite in a quantitative representation/scientific analysis. Also, different attributes cannot be used to a given end at the same time. Therefore, water can be characterized as a resource for one end at each time. For example, if water falls in a dam we cannot drink it at the same time. But it can be drunk later. This brings us to another idea: when water stops being a resource for one end, it can still be a resource for another purpose if it still has the attribute to be so, if the combination of

[3] This is a great example on how different understanding arrive to different points from the same lace. Ironically, this punch line has been used to support two interpretations that radically oppose: the fixity (Gregori, 1987) and dynamicity (Bridge, 2009) of the concept of resource. While fixity argues that humans can always find a way to transform an element into a resource -a way to solve a problem-, the latter implies that when some unique elements lose the ability to solve problems, those resources will not be available any more. This would be the case if all the water of the planet became salty and there were no other element able to remove thirst. Zimmermann already turned around dynamicity when he stated that "nature sets the limits within which man can develop his arts to satisfy his wants" (Zimmermann, 1951)and that the "human is not only a creator of resources, he is also a destroyer" since "he cannot help that [resources] are dissipated in use"(Zimmermann, 1951).

characteristics is still suitable to give it that attribute. But we will go back to this idea later, when we speak of water as a flow or a fund.

Therefore the end for which water is going to be used is part of the definition of water as a resource. The decision of whether a quantity of water is a resource for a given end or not –if it has a relevant attribute or not- depends mainly on two parameters: (i) which characteristics are included to define the attribute that gives it the status of resource; and (ii) how the characteristics are valued. For example, in Europe, we do not consider the level of purity or cleanness of Ganga River to grant it with the attribute "drinkable", but in India the cultural meaning do so: as it is "Mother Ganga" it is not necessary to check the purity of the water. Regarding the valuation, the characteristics can be valued in two ways: predicative and impredicative (Giampietro et al., 2011). The information derived from the predicative valuation is "context-independent". It gives an "objective" indication about the definition of an attribute, which is independent from the context and the goal of the analysis. When the valuation of the characteristics is done in an impredicative manner, the resulting information is "context-dependent". Here, the relevance of the value of the characteristic used to define the attribute depends on the context. Some examples are shown in figure 1.

Figure 1. Possible ways of valuing the water characteristics in order to assign a water mass an attribute

Assigned attribute	Drinkable	Drinkable	Abundant	Scarce
Characteristic included	Cultural meaning	Purity	Quantity	Quantity
Predicative Valuation	--	"Water is drinkable if the content in chlorine is under 1 mg/l"	"Water is abundant if the rain is over 700 mm"	"Water is scarce if the rainfall is under 200 mm a year"
Impredicative Valuation	"Water is drinkable if the river is our mother"	(Including personal likes) "Water is drinkable if it does not taste like chlorine"	(Including Time & Geographical reference) "Water is abundant if there is more supply than demand"	(Including Time & Geographical reference) "Water is scarce if there is more demand than supply"

As the examples in the table show, an impredicative definition is more flexible, since it is semantic and can be adjusted to different situations/contexts. Yet it is more difficult to include in a semantically closed analysis. Water has been described in depth by many different scientific disciplines but by taking into account just one narrative and one scale at the time. Hydrogeology studies the chemical characteristics; Economics focuses on the economic use of water flows used by social systems and how to manage them, Anthropology assesses water's cultural value, Geography draws its location, etc. However, we observed earlier that the end use of water affects the definition of water as a resource at different scales –those required to describe water use. Therefore, it is essential to include impredicativity in the definition of water as a resource, especially in order to study water as an Ecosocial Asset. *That is to say, the valuation of water as a resource is always dependent on the context*. Water is unique precisely because of this unconditional need of an impredicative definition and therefore the methodology used to analyze water use must allow for impredicative characterization of it as resource.

In relation to the impredicativity of the water resource, the concept of metabolism based in the Flow/Fund model makes it possible to develop a quantitative analysis of water use that takes into account these qualitative aspects. This is possible by integrating in the definition of the indicators of waster use a definition of the attributes of the water resource based on an impredicative characterization that includes a context-dependent valuation. Here is an example: in rural China human excrements (a waste) represent a valuable resource for fertilizing the soil, in Beijing, still in China, human excrements are a problem requiring waste treatment plants. In these two situations, we are focusing on the characteristics of the human excrements "per se" (the flow), we would find exactly the same characteristics in rural areas and in the city, what is different is the interaction with the context (its role as a flow or as a fund).

As we mentioned above, regarding the definition of water use, another basic epistemological issue is the scale. Following the natural water cycle, we can represent water flows which are "consumed" (no longer available) by social or natural systems at different hierarchical levels. The concept of "consumption" in this interpretation does not necessarily refer to the disappearance of a given quantitative mass of water, rather it may refers to the loss of qualitative attributes of the water resource, that is, the resource is consumed. For example, a cubic meter of drinkable water can be "consumed" if human-driven bacterial contamination prevents its use as a safe drinking source.

That is, when we define non-consumptive uses of water we must refer to a process in which none of the relevant attributes used to characterize its potential uses is changed. Following Zimmermann's definition of resources and Aguilera's Ecosocial Asset, we argue that social and natural systems do not "consume" water, when considered as a natural element, since the amount of water remains constant on Earth. On the contrary, they may consume the resource, the Ecosocial Asset (and this brings us to the importance of making a distinction between fund, stock and flow elements). Once the values of its characteristics have changed and the relevant attribute of the water resource has been consumed, the water is no longer the same resource for the same purpose anymore. In this case, either the natural cycles or human driven processes are required to give it back the original characteristics that made it an Ecosocial Asset, a resource.

2.2. The functions and services of the water resource

An important issue arises here about how to classify the benefits that the resource water provides in order to identify what are the systems using them, the systems that are relevant for the analysis of water use. For other resources there are lists this benefits, which have been properly defined and classified - see for example the study of exergy by Warr et al. (2008) - but this is not the case with water. In relation to this point, the Ecosystems Services narrative (ES) offers an effective frame in which functions and services of ecosystems can be evaluated. Because of this, recently ES is not only becoming important in the academic definition of natural "resources" but also is slowly stepping into the governance world, so we add on it to assess the importance of water.

Up to date, the resource water has been defined under this narrative as a service provided by ecosystems (de Groot et al., 2002). They provide a list that frames ecosystem functions and services. They clearly distinguish between: (i) "ecosystem services" - as those ecosystem functions that are actively used, enjoyed or consumed by humans; and (ii) "ecosystem functions" - as those parts of ecosystem's processes and components with capacity to provide services to humans to fulfil a human need. In this view, *Water (element) supply* is considered to be a function provided by ecosystems, since they maintain and provide fresh water. Through this function, ecosystems provide an essential service to humans: the required flow of Fresh water which is so important for socio-economic systems. Besides the direct supply to humans, ecosystems provide the additional function of *Water regulation* that prevents from floods, maintain green water irrigation and regulate natural water flows. Logically, the good status of the dynamics of water functions and services at all levels depends upon the proper interaction across scales of the various flows, funds and stocks.

The Millennium Ecosystem Assessment (MEA) (Aylward et al. 2005) goes a bit further by establishing a conceptual framework were the element water is understood as an ecosystem function which provides services itself. There, fresh water is recognised as much more than a service provided by ecosystems. Authors argue that, together with the hydrological cycle, the flow of fresh water is also the basis to sustain inland and freshwater ecosystems. By doing so, fresh water provides "cultural, regulating and supporting *services* that contribute directly and indirectly to human well-being". Therefore, in this work, they present an integrated view of the role of water not only as a function given by ecosystems but also as a provider of services for the social system as seen in table 1.

Table 1. Ecosystem Services Provided by Freshwater and the Hydrologic Cycle. From Aylward et al. (2005)

Ecosystem Services Provided by Fresh Water and the Hydrologic Cycle Many of the provisioning, regulatory, and cultural services can be enhanced through development of water resources (large-scale navigation can be increased by creating slackwater systems using dams); however, there are often off-setting losses or trade-offs between these service categories, such as loss of rapid transport downstream to locals or those seeking recreation.		
Provisioning Services	Regulatory Services	Cultural Services
Water (quantity and quality) for consumptive use (for drinking, domestic use, and agriculture and industrial use) Water for non-consumptive use (for generating power and transport/ navigation) Aquatic organisms for food and medicines	Maintenance of water quality (natural filtration and water treatment) Buffering of flood flows, erosion control through water/ land interactions and flood control infrastructure	Recreation (river rafting, kayaking, hiking, and fishing as a sport) Tourism (river viewing) Existence values (personal satisfaction from free flowing rivers)
Supporting Services		
Role in nutrient cycling (role in maintenance of floodplain fertility), primary production Predator/prey relationships and ecosystem resilience		

In relation to these conceptualizations, we propose the use of "water services" to refer the capacities used by **societal metabolism.** "Water functions" refer to those provided to Earth climate regulation and **ecosystems metabolism,** which we define below. That is, we understand that water should not be considered a resource only because it provides the services described in table 1 to societies but also, because it renders functions that are essential for healthy ecosystem components (structural maintenance) and processes (functional maintenance).

Within this framework, we can make a distinction between the part of the water of a territory that can be appropriated in order to be used by humans (at the local scale) and the part of the water of a territory that has to be left in the metabolic pattern of local ecosystem to guarantee the reproduction of its structures and functions (at a larger scale). When moving to an even larger scale (a global scale) we can also define certain volumes of water which are required to provide functions essential for the maintenance of life on Earth (the closure of the water cycle). Therefore, when adopting this larger scale, we find an additional function which can be associated with flows of water on the planet. This definition of water is closer to that of Ecosocial Asset. As these functions and services are different at different hierarchical levels, it is important that we learn how to perceive and represent the role of water in a metabolic pattern across different scales.

2.3. How can water be used? Water as Flow and Fund

Georgescu-Roegen (1971) argued that two analytical models are mostly used in Economics in order to represent a productive process: the flow model and the stock model. This affirmation is still valid today. In a flow model the only matter of importance is the flow crossing the boundaries of the system. The stock model on the contrary does not care about what is crossing the border. It focuses on the differences found when looking at the system in two different moments. The author debates the relation between them to conclude that the definition of flows as the variation of stocks is not valid since it supposes that the differences of the stocks in two moments are due to the flows crossing the boundaries of an economic process. But not all the flows are related to the increase or decrease of a stock.

For this reason a different analytical model was proposed by GR in order to include qualitative change. Actually, in a productive process, some of the elements that are getting in are never getting out, nor becoming a stock inside the process, as, for example, natural resources and energy inputs. Some other elements flow only out, as products. Others are getting in and out unchanged.

The first and second categories of elements can be defined as Flows and the third as a Fund. After GR, *a Fund* is an element that remains ''the same'' over the duration of the representation. To remain the same means that the element is used because it provides some services but is not consumed. *Flows* are those elements that are consumed or created during the process. Main flows proposed by GR are Resources, Intermediate Inputs, Fund Maintenance Flows, Products and Waste. The main Funds are Capital –as machinery-, Labour -as provided by Households- and Ricardian Land -as the provider of support and absorber of solar energy. To be precise, funds do change because these services are "decumulated" (a man gets tired during a day), but their efficiency is admitted "intact" *within the representation of the process* because other flows are used to maintain it. Therefore, the definition of fund-elements entails a qualitative connotation in the analysis, since fund-elements imply an overhead for the maintenance and reproduction (human workers need food and rest to recover in the short run and in the long run they need replacement in the form of dependent persons at the level of the household).

Following these definitions and reflecting on the discussions and definitions discussed in Section 2.1 and Section 2.2, we can easily recognize that when operating in a multi-level setting, water can be used as both, a flow-element and a fund-element. This distinction adds the qualitative aspect in the quantitative analysis of water use. Obviously, there *is always a certain amount of water that is used* and therefore the analysis will always be related to this quantity, and thus quantitative. The qualitative aspect is included when we define water first as a resource and later as a flow or a fund.

The classification depends on the time and material boundaries chosen for looking at the process. This fact points directly to the issue of scale that the adoption of the Flow/Fund model explicitly addresses. In the Flow/Fund model the pre-analytical choice of a scale is essential in determining the definition of the boundaries since as GR argued, “the question of whether a factor is classified as a fund or as a flow in the analytical representation of an actual process depends upon the duration of that process” (Georgescu-Roegen, 1971). That is, in the Flow/Fund model: “the temporal and material boundaries of an economic process are neither arbitrary nor are they independent of each other” (Farrell and Mayumi, 2009). Boundaries are not arbitrary since this selection is made in a pre-analytical step by the analyst and is highly dependent on his/her perception of the relevant aspects of the system under investigation (Giampietro et al., 2009). Accordingly, we can conclude that the adoption of a substantive fix classification of water as either a flow or fund, is not useful for the purpose of analysing metabolic patterns. Therefore, after having acknowledged the importance of the pre-analytical choice of scale and faced the crucial choice of what attributes have to be considered to define “water” and “water use”, it is required to appoint some key issues that must be dealt with when defining water as a flow or a fund.

The key question to be considered when trying to do this classification is “*what do we consider a qualitative change”* in the “water resource” (at the scale of the representation) that will convince us to consider it as either a flow or a fund. In this sense, when the quantity of the element water is changing state during the process – e.g. water evaporating into clouds - or turning into another substance – e.g. water used to make soft drinks - then the resource must be clearly classified as a Flow. When neither the quantity nor its attributes (no resource consumption) are changed, then the resource “water” can be considered as a fund element. The concept of water use emerges when the resource is consumed, that is, when any of the attributes of the resource is consumed due to the change in the value of the characteristic. This may be the case of, for example, the water needed to produce energy in a hydroelectric station (when the change in potential energy is a relevant attribute to characterize that quantity of water as a resource). That is to say, when water falls from the top of a dam to a river and its potential energy is transformed into the movement of a turbine which generates electricity, its quantity and cleanness have not been used. In this case, we can say that the element water is the same, but the resource water has changed since in order to be able to generate electricity again by the same method, we would have to spend a certain amount of energy to pump it back to the same height. In this case, water would be a flow. There will be an entrance of resource and an exit of element.

As we appointed before, that quantity of water might be a resource for other purpose but not for the same one again. As a result, we consider that *a **qualitative change** in water occurs when one or more attributes cannot be used again for the same purpose during the representation of the process.* On the other, hand if the only relevant goal of the analysis is to assess the availability of water for irrigation in a zone downstream the hydro-electric plant, the loss of gravitational gradient will not be considered as “a use” of water in relation to irrigation, since we are looking to a different perception of water resource. Again, the categorization of a certain amount of water as flow or fund will depend on whether or not the water attributes can be reused over and over in a specified process at a specified scale, as would be the case for navigation. This is the reason why an integrated assessment of the water metabolism requires a semantically open protocol of accounting (a grammar) which can be tailored on the specific situation and goals of the analysis.

Whenever a given quantity of water is required in a constant flow in time, and not all at once, that water quantity has to be considered a flow associated with a given water service. If 1000 m^3 of water-resource are used to refrigerate a thermal power station during the time of the analysis, they are not needed all at once, but as a constant flow whose dimension will depend on how quick the attribute “heat absorber” of the resource is consumed. If the water needed is used all at once during the duration of the analysis, as in the case of navigation, soil moisture, etc. then we have to considered such a quantity of water a fund. Within this perspective the stable and predictable flow of water of a river that is needed all at once – in an ecological narrative - is a clear fund for ecosystems. The ecosystem functions that water provides can be associated with the need of preserving a specific structures and functions in which the biological activities of the ecosystem can flourish.

As we mentioned before, as a fund water provides some services to social systems that decumulate. In order to understand which are *the services* that water provides as fund and *how do they decumulate*, we have to consider those uses of water that do not consume its attributes. Clearly, water availability for ecosystems is a standard predictable pattern guaranteed by natural processes according to which ecosystems distribute on space[4]. Therefore, it can be used as a variable to answer the question “*what the (aquatic) ecosystem is?”* and thus can be defined as a fund. Water as a provider of services for social uses is not usually considered as a fund because normally one or more water attributes – those which give the concrete relevant service in each case services- are consumed in order to create economic value (Aguilera Klink, 1994).

The interesting relation is that since water also provides *functions* to ecosystems, the social systems inserted on them *might damage the role of water as fund for ecosystems*. It is well known that humans can generate a reduction in the size and quality of natural water funds by over-drafting flows out of them. When polluting or dwindling, water characteristics do also suffer a change that might vary the attribute and *water functions are decumulated*. Therefore, when dealing with the analysis of water metabolism we find a new typology of funds, which are different from social funds (capital, labour, land). Social funds may decumulate because of the activity of the own system. In the case of water the decumulation of ecological fund elements often happens not because of the own ecosystem dynamic but rather because of human impact on them. In this way, the identity of water natural funds should be considered as an external constraint to the water flows used by the social systems (determining inputs and outputs). The preservation of the identity of natural funds must be used as limitation to determine the availability of flows of water that can be used for the Societal Metabolism (both on the supply – withdraw – and the sink side – pollution).

2.4. Water in the Metabolism Framework: the Water Metabolism

Since the characterization of water as a Fund element of ecosystems limits the amount of the resource available to be used as Social Flow, the study of the pattern of societal metabolism of water (the water use of the compartments inside the society) is insufficient to properly understand

[4] Mean yearly rain is an indicator of type of climatic conditions determining the sort of ecosystems established in a territory, for example.

the stability of resource dynamics. It must be completed by the study of the pattern of ecological metabolism of water referring to the ecosystems embedding the societal metabolism (direct and indirect use) and in cascade to a larger scale analysis of the Earth Metabolism, when studying at a larger scale the constraints associated with the integrity of the water cycle. Getting back to the analysis of physiological metabolism, we can individuate an important difference between “the metabolism of a cell” (structural and functional process) and the “metabolism of glucose” (a specific chemical substance present in the metabolic pattern). The first one study the set of reactions expressed by the various elements operating inside the cell, while the second focus on the paths of different chemical substances associated with the transformation of glucose, how this is composed and decomposed. This example illustrates the possibility/necessity of using two narratives about metabolism: one related to the systemic study of the metabolism of a system, the other related to the metabolic taxonomy associated with the changes of an element.

This distinction between possible non-equivalent narratives used for metabolic studies is important for all resources which can be analyzed in terms of flow/fund (material flows, energy flows, money flows). However, this distinction becomes absolutely fundamental when dealing with analysis of water metabolism. In fact, in this case the amount of the resource (quantity of water, cleanness of water, etc.) available for a specific system at a given level depends on the organisation and functioning of the higher level system and at the same time is affecting it[5].

In general terms when dealing with extractive resources (such as fossil energy and minerals) the flow of resources used by societies can be described as unidirectional flows going from larger scale elements to smaller scale elements. A given amount of resources from the Earth goes into ecosystems, then into social systems, then into specific sectors, to be used and transformed in something else. None of these resources can go easily back to the upper levels getting back the same original form. On the contrary, water when considered as an element (and not a resource) does it. Since the amount of total element water on Earth is practically constant, we can imagine the water cycle on this planet as a gigantic metabolic pattern, at the scale of the whole biosphere, guaranteeing the reproduction of higher level fund elements of water metabolism (water in the cycle infiltrates to aquifers, runs to the oceans, evaporates to the atmosphere, etc.). This creates a set of expected relations between parts and wholes at different hierarchical levels.

This deep hierarchical relation among different metabolic patterns (the water cycle of the entire planet, the water metabolism of ecosystems, the water metabolism of societies) explains why, water metabolism cannot be understood (perceived and represented) by looking only at the water that flows through the economic process. In order to properly define the sustainability of a given profile of water use, a cascade of metabolic patterns defined at different levels must be taken into account. For the sake of simplicity, and keeping in mind that the boundaries of the systems must be defined by the analyst, we distinguish three general levels in the Study of the Water Metabolism: Earth Metabolism, Ecosystem Metabolism and Societal Metabolism of Water.

The *Earth Metabolism of Water* is typically known as the Water Cycle. As scaling up implies higher complexity, the Earth Metabolism of Water is so complex (encompassing so many

[5] That is to say, the water metabolism is impredicative.

relevant levels and scales) that the idea of deterministic assessment it is utopic. In spite of that, we can safely say that its continuity is essential for the '*reproduction'* of the resource water for both social and ecosystems. However, this reproduction is not happening automatically. In order to renew the characteristics and services of water at the level of the whole planet, the use of 44000 TW -one third of the total solar energy reaching the Earth- is needed (Taube, 1985). This amount represents 4000 times the total amount of exosomatic energy controlled by humankind in 1999, which was around 11 TW (Giampietro, 2003). The water cycle discharges the high entropy generated by the ecosystems from the planet surface to the outer space, allowing an average temperature of 15ºC on it. This way, Earth Metabolism of water represents the main energy distributer and temperature regulator of the Earth. Therefore, it guarantees the conditions needed for terrestrial ecosystems to survive and produce a store of energy in the form of potential energy and biomass. It also stabilizes aquifers, rivers, lakes and seas by providing a standard quasi-predictable pattern in the medium term. The water cycle is the clearest fund element defined at the level of the whole planet. The amount of water in the cycle is given and it remains nearly the same year after year (with different profile of allocation of the water among the various compartments of the cycle). Social and eco-systems do also influence the water cycle by means of plants transpiration, favouring infiltration to the ground, retaining water on soil or dams, etc.

In order to reach the social system, water has to cross the ecosystems level. At this level, we can define the main reservoirs of water, such as rivers, aquifers, the rain or the sea, established by ecological process. These processes make water available for the own ecological systems and for the social systems, assuming that the social system in question knows how to collect the required water. In this framework, water reservoirs are usually fund-elements maintained by the water cycle[6]. Within this multi-level view, the *Ecosystem Metabolism of Water is* an intermediate level bridging the very large scale of the global water cycle to the local scale of the consumption of water flows by social systems. At the ecosystem level, water allows life by providing the essential functions for ecosystems and local conditions of reproduction of individual organisms, as previously mentioned in section 2.2. These functions (and the relative processes) can be described in quantitative terms, by the various scientific disciplines dealing with the role of water in ecology and biology.

The three levels framing the analysis of the metabolism of water outside the metabolic pattern are very important to study the stability of boundary conditions. However, it should be noted that, when coming to the perspective of the humans living in the society (e.g. their preferences and their definition of usefulness) it is the *Societal Metabolism of Water* that becomes the most important level of analysis in relation to the desirability and technical and economic viability of water uses. The set of levels and scales to be considered for the analysis of the metabolic pattern of water (whole society, functional compartments, individual plants or household, individual tasks or individuals) has been widely developed for the analysis of the metabolism of other materials use and, especially, for energy. As a consequence, there are important synergisms to be gained by integrating the analysis of water metabolism with the analysis of other metabolic flows. For example, in the analysis of energy metabolism there is a fundamental distinction between

[6] In important to note that at this scale only parts of the water cycle will be seen, such as rain or evaporation which will be flows maintaining the funds 'reservoirs'.

endosomatic and exosomatic transformations of energy. The former considers those processes occurring inside the human body to maintain and reproduce the individual. The latter refers to the processes occurring when the human being is organised in society, producing and consuming services and goods in order to maintain and reproduce social structures and institutions. This distinction can be kept for assessing social water use.

According to the different services water provides, Arrojo (2006) divides water uses into three types. This distinction represents the choice of attributes of water for our Study:

(i) Life-water. This is the water that provides the covering of the basic needs of a person and sums to approximately 30-40 litres per person per day;

(ii) Citizenship-water. This concept involves a higher level in the spatial scale and refers to the water typically included in the supply and sanitation (public-community) services that reach about 100-120 litres per person per day;

(iii) Economy-water. This is the water used to create economic value. This kind of demand includes the water needs of economic sectors and reaches between 50 and 80 % of a society's total water use, depending on how much Agricultural sector the society has.

Following this classification, and using the categories used in the MuSIASEM approach we can identify the Arrojo's Life-Water as the amount of water used for endosomatic consumption. In the MuSIASEM approach endosomatic consumption refers to flows required for the physiological maintenance and reproduction of the human body. The other two categories would refer to Exosomatic consumption of water In the MuSIASEM approach the total amount of human activity (defined at the level n – the whole society) is divided (at the level n-1) into two compartments: the households (human activities outside the Paid Work sector); and the Paid work sector (human activities in the aid Work sector). In relation to this distinction we may imagine to associate the concept of Citizenship Water to the label "exosomatic consumption of water at the level of the household" and the concept of Economy-Water to the label "exosomatic consumption of water in the compartment of Paid Work".

3. Water Metabolism studied with MuSIASEM

3.1. Intro to MuSIASEM

There is a methodology - Multi Scale Integrated Assessment of Societal and Ecological Metabolism (MuSIASEM) - developed to handle, in quantitative analysis, different definitions of a resource at different levels of analysis (Mayumi and Giampietro, 2000a, 2000b; Giampietro, 2003; Giampietro et al., 2009). This methodological approach is based on an accounting grammar which allows us to analyze the pattern of production and consumption of goods and services of a given society (associated with a given level of economic development) simultaneously across different levels of analysis and in relation to different dimensions of analysis. In this way, it can handle information referring to demography, economics, ecology, and technical disciplines. The MuSIASEM approach integrates various theoretical concepts and combines different methodological tools coming from different fields: (i) Non-equilibrium Thermodynamics applied to ecological analysis (Odum, 1971, 1983, 1996; Ulanowicz, 1986) (ii) Complex Systems Theory

(Zipf, 1941; Rosen, 1958, 2000; Morowitz, 1968; Kauffman, 1993); and (iii) The flow-fund model of Georgescu-Roegen developed for Bioeconomics.

For a short overview of this approach and its application see (Giampietro et al., 2009). Theoretical discussions and examples of applications of this method are available in two books (Giampietro, 2003; Polimeni et al., 2008; Giampietro and Mayumi, 2009) and more than 30 papers. Empirical analyses of energy metabolism have been conducted on countries such as Ecuador (Falconi-Benitez, F., 2001), Spain (Ramos-Martin, 2001), Vietnam (Ramos-Martin and Giampietro, 2005), China (Ramos-Martin, Giampietro, et al., 2007) and Catalonia (Sorman Hadiye et al., 2009). The MuSIASEM approach can be used in the government arena as well. Recently a study for the Government of Catalonia, over the period 1995-2005 was released, which has the goal of informing energy policies in the face of the global energy crisis (Ramos-Martin, Cañellas-Boltà, et al., 2007).

Applications to rural systems metabolism have also been undertaken in Laos (Serrano and Giampietro, 2009), Guatemala (Mingorria and Gamboa, 2011), Mexico and Argentina (Arizpe et al., 2011). New applications are now initiating on conflicts analysis (Barbas Baptista, 2010). This paper is the first attempt of using this scheme to water metabolism analysis.

Our interest in using it lies in the fact that MuSIASEM is the only method that we found which is able to explore the interaction among the different levels of Water metabolism: outside the society to study external constraints and inside the society to study internal constraints. Because of this fact, it makes it possible to explore the cyclic relations between resource dynamics and social dynamics. Moreover, building on the rationale of the Flow/Fund model, MuSIASEM makes it possible to discuss and decide about the fund variables to be used to describe *what the system is? i.e. which is the identity of the system to be maintained,* and flow variables to define *what the system does, i.e. how does it reproduces its identity,* in relation to both internal and external constraints. For all these reasons we believe that the MuSIASEM approach is a promising methodology to study Water Metabolism.

3.2. Proposal of an analytical framework for multi-scale analysis of societal and ecological metabolism of water

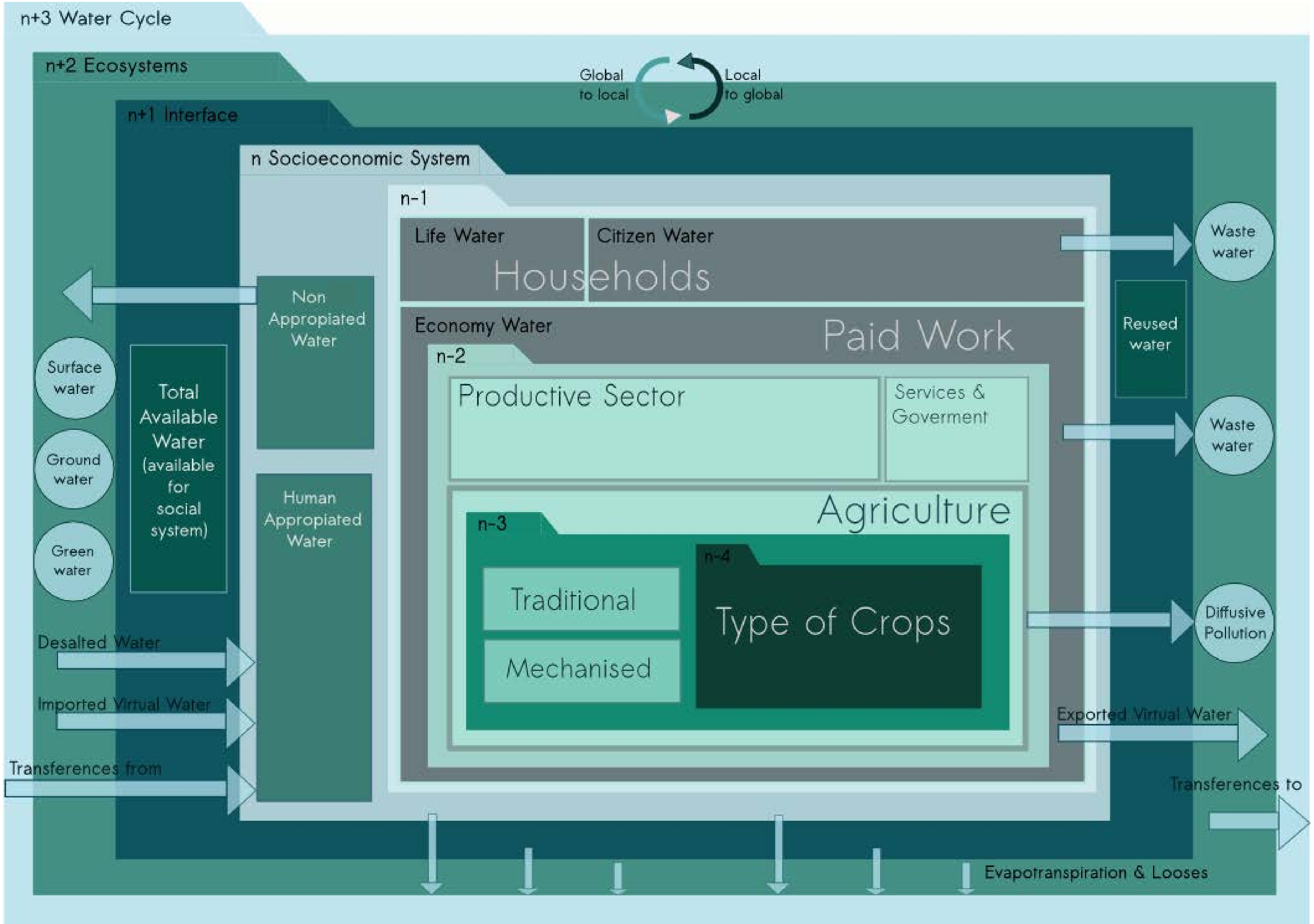
Let us name the level of analysis of the metabolic pattern of the whole society (described over the duration of one year) as the level *n*. From here, we can set a hierarchy of levels on which organize the analysis. The interface Ecosystem and Societal Metabolism will be related to the interaction of events described on the two levels n+1/n. From here, we can look at the stability of the fund elements of the ecosystem metabolism on the two levels n+3/n+2 (global/ecosystem), and we can look at the performance of the societal metabolism, looking inside the society (a black box at the level n), to water uses taking places at lower hierarchical levels (n-1, n-2, . . . n-x). In this way, our analysis can be related to definition of water flows associated with narratives that go from the stability of the water cycle to the drinking of a glass of water (in the endosomatic metabolic pattern of individuals). In the previous sections we discussed the importance of considering water as either a flow or a fund depending on the chosen narrative (referring to different processes and the roles the water plays in them). We also highlighted the dependency of the analysis on the purpose of the study which determines the definition of the system and thus the descriptive domain[7] to be adopted for quantification. Here, we propose a general multi-scale framework based on these concepts. We set formal categories (i.e. extensive and intensive variables) for analyzing water metabolism in a way able to include the interconnection of both systems reflecting the multi-functionality of water across different scales and dimensions. The set of variables generated by this categorization can be linked to other funds (e.g. categories of Human Activity and Colonised Land) and flows (e.g. energy and monetary flows) as described in previous applications of the MuSIASEM approach.

The MuSIASEM grammar can be used to analyze the congruence of flows and funds definitions across levels, since it establishes a set of expected relations over the values, which can be taken by the combination of extensive variables and intensive variables defined across different levels. Taking advantage of this characteristic, the analysis of the societal metabolism of water (water flows in the different compartments of human activity and land uses) can be associated with other MuSIASEM analyses – e.g. energy and water per hour of labour and hectare of land use in relation to production of added value, in the agricultural sector or for typology of agricultural product.

Therefore, we adopt the same two fund variables used by the MuSIASEM approach: (i) Total Human Activity; and (ii) Total Colonised Land. These two variables represent two non-equivalent definition of the size of the metabolic system – e.g. a given social system (be a village, a region or a whole country), which can be defined in terms of a given amount of total human activity per year (population x 8,760 hours) or as a given amount of Colonized land. As explained, to operate the MuSIASEM grammar we have first to set “the level *n”* of reference used to define the relevant definition of the “whole social system” for the purpose of the analysis. Then we can characterize the metabolic pattern of this system over one year. The extensive variable related to the fund element – e.g. Human Activity and Land Use – is used to define the total size of the system. However, when choosing the taxonomy of fund elements defined on the lower levels (what set of categories of human activity are expressed in the different compartments within the society) the analyst is forced to define the identity of the metabolic system (across different levels and scales). At this point, we have to define flows - such as water, exosomatic energy, agricultural production, GDP, fertilizers, waste, pollutants - that can be referred to a unit of human activity or a unit of colonized land, considered in the different categories. That is, by combining the flow element with fund element we can obtain a set of intensive variables such as: water consumed per hour of activity in the economic sector of building and manufacturing; water consumed per hectare in corn production; water consumed per hour of human activity in the household sector. The intensive variables are used to describe “what the system does” in relation to the definition of structural and functional compartments of the society. The combination of the analysis of extensive and intensive variables makes it possible to study how the society reproduces its own structures and functions in relation to both internal and external constraints.

[7] This means “the representation of a domain of reality that has been individuated on the basis of a pre-analytical decision on how to describe the identity of the investigated system in relation to the goals of the analysis”(Giampietro, 2003).

Figure 2. Analytical framework proposed under the definitions of water given



Of utmost importance is to point out that the set of the formal categories to be included in the taxonomy of human activities or land uses is semantically open. This makes it possible to fit the spatial and political reference of specific case. In the second part we will present two case studies, which are both meso spatial levels from different scopes –political and natural - and both are analysis that include a social system whose characteristics are driven by the European-western-northern culture. If we had to analyze with MuSIASEM impoverished economies, for instance, with subsistence agriculture, or with water supply completely privatized, with a serious problem of poverty and social exclusion we would have to adopt a totally different selection of taxonomy to describe the fund elements and the relevant flows.

Figure 2 represents the proposed analytical framework of analysis. The highest level is *n+3,* where the water cycle performs with its flows of evapotranspiration, precipitation, infiltration etc. This level is typically studied in meteorology and classical hydrology. The following level is *n+2* where we find water primary sources in a territory, including aquifers, rivers, lakes, soil etc. They constitute the reservoirs of water. Sea water could be included now that desalination is a new source of fresh water. This is the water available for ecosystems processes, but also for social appropriation, and it is highly related to the land use pattern.It follows *n+1,* which represents the interface between natural and social systems and includes that part of water primary sources in *n+2* that are extracted by the social system. This include water ‘regulated’ with dams, water extracted from aquifers, desalted water from the sea, reused wastewater, transfers of water from external territories and imported virtual water. Statistically, this is reflected by water withdrawal or availability.

From level n down, we find water actually used by the social system, what we call Human Appropriated Water, as well as that part of the available water that is left or returned to the natural bodies (Non Appropriated Water). Here we differentiate the three kinds of water of (Arrojo, 2006) which in the MuSIASEM scheme split between the consumption side –Households- and the production side -Paid Work- sectors. We include life-water and citizenship-water in the former and economy-water in the latter. Within the economy-water, level n-2 splits in all those sectors consuming water. The categories chosen will of course depend on the context but agriculture will likely bear the higher burden. The division of the split systems depends on the analysis, as it does in other MuSIASEM applications.

The flows of wastewater -both point-source and diffusive- return to the *n+1* and *n+2* levels of ecosystems and into potential water sources. There is a continuous outflow from the social system to *n+3* with evapotranspiration and losing in the water supply chain, which should be accounted in each step from one level to the lower one. Finally, exported virtual water and transferences to other territories should be also included as negative flows in the balance.

Table 2. Definition of Extensive variables

Level	Acronym	Variable	Explanation	Unit
Extensive variables for water				
n+3	EVT PPT I RO	Evapotranspiration Precipitation Infiltration Run-off	These are the normal variables used to characterised the water cycle balance in a territory. They are flows within the cycle.	hm^3/year or mm
n+2	AW_{GW} AW_{SF} AW_{G}	Available Water in: Groundwater Surface Water Green Water	Water available for ecosystems development, including blue water (ground and surface) and green water (soil and vegetation)	hm^3/year
n+1	TAW	Total Available Water	That part of the n+2 stocks that can be appropiated by the social system plus a) reused and desalted wastewater, b) transferences from other territories and c) virtual water imported	hm^3/year
n	HAW NAW	Human Appropiated Water Non Appopiated Water	That part of the Total Available Water that the social systems consumes in reality That part of the Total Available water that is left in the stocks as environemtal flows due to political decision at this level	hm^3 /year
n-1	AW_{HH} AW_{PW}	Appropiated Water by Households Appropiated Water by the Paid Work sector	Life-water and citizenship-water used in physiological overhead at households Water-economy used in the different economic sectors of a social system, including social services	hm^3 /year
n-2	AW_{AG} AW_{PS} AW_{SG}	Appropiated Water by: Agriculture Producttion Sector Services and Goverment	Water consumption in the different sectors of an economy in a year	hm^3 /year
n-3	AW_{EAG} AW_{IAG}	Appropiated Water of Traditional or Ecological and Mechanised Agriculture	Water consumption in different modes of agricultural production, aggregating different types of crops	hm^3 /year
n-4	VW_{CROPS}	Virtual Water associated to different crops	At this level the benchmark is the virtual water or total water embeeded in a crop per year.	hm^3 /year
Extensive variables for Gross Added Value				
n	GVA (FLOW)	Gross Value Added in constant prices	Gross added value for the whole economic production of the system	10^3 Euro/year
n-1	GVA_{PW}	Gross Value Added for Paid Work	Gross Value Added for whole Paid Work sector	10^3 Euro/year
n-2	GVA_{AG} GVA_{PS} GVA_{SG}	Agriculture (AG), Productive Sectors (PS) and Services and Government	Gross Value Added for the different sectors of the economy in the system	10^3 Euro/year
n-3	GVA_{X} GVA_{Y}	Crop x and livestock Y production	Gross Value Added for the different products	10^3 Euro/year

Table 2 shows the extensive variables (defining the size of the compartment) we define for Water and Gross Added Value and Table 3 the intensive variables (ratios resulting from combination of intensive and extensive variables) used in the case studies presented in the following sections. All the variables are referred to a period of accounting of one year, which is the most common one in MuSIASEM.

In Part II, we show the potential of MuSIASEM in the assessment of water use. First we present a characterization of the metabolic patterns of the water use for Catalonia (North Spain). Then we present an application to the assessment of the WFD system of river basin planning and management set in the River Basin of Andarax River, in Almeria, South Spain.

Table 3. Definition of Intensive variables

Level	Acronym	Variable	Explanation	Unit and calculation
Intensive variables for water				
n	WUR (FLOW/FUND)	Water Use Rate for the whole Society.	Water used per hour of human time in a society (both as consumer and producer), indicator of Metabolic Intensity of Water	m^3/h HAW/THA
n-1	WUR_{PW} WUR_{HH}	Water Use Rate for: Paid Work (PW) and Households (HH)	Water used per hour of human activity in Production side (PW) and the Consumption side (HH)	m^3/h HAW_{PW}/HA_{PW} HAW_{HH}/HA_{HH}
n-2	WUR_{AG} WUR_{PS} WUR_{SG}	Water Use Rate for: Agriculture (AG) Productive Sectors (PS) Services and Government (SG)	Water used per hour of human activity in Agriculture (AG) Productive Sectors (PS) Services and Government (SG)	m^3/h HAW_{AG}/HA_{PW} HAW_{HH}/HA_{HH}
n-2	WD_{AG} (FLOW/FUND)	Water Density for Agriculure	Water used per hectare of Colonised Land for Agriculture (AG)	m^3/ha HAW_{AG}/CL_{PW}
Intensive variables for Economic Productivity				
n	ELP (FLOW/FLOW)	Economic Labour Productivity	Added value generated per hour of activity	€/h
n-1	ELP_{PS} ELP_{HH}	Economic Labour Productivity for: Paid Sector and Households	Added value generated per hour of activity in the Paid Sector and Households	€/h
n-2	ELP_{AG} ELP_{OPS} ELP_{SG}	Economic Labour Productivity for: Agriculture, Other Paid Sectors or Services and Government	Added value generated per hour of activity in Agriculture, Other Paid Sectors or Services and Government	€/h

Part II: Applications of MuSIASEM to the study of the societal metabolism of water

4. Characterization of the metabolic patterns of water use to assess a productive structure: the case of Catalonia

Catalonia is a region in the north east of Spain, with a population of about 7.5 million people, mainly concentrated (about 5 million) in the metropolitan area of Barcelona. Its Regional GDP is about 150,000 million euro (about 29,000 euro per capita). The region's water budget comes from two different natural spaces: The Internal Basins of Catalonia (CIC) which holds 92% of the population and represents only 52% of the surface; and the Intercommunity Basins (CIN) –whose main source of water is the Ebro River.

4.1. Description of the system and general view

In this case study, we do not perform any fieldwork, thus the definition of the recollection of the data was made before by the statistic institutes. Data sources are:

- Spanish Statistic Institute (INE) for all Water use Data and Gross Added Value (GAV) of Spain
- Catalan Statistic Institute (IDESCAT) for GAV of Catalonia
- Department of Environment of the Catalan Government for detailed data on crop water use
- The Department of agriculture of the Catalan government for crop production and surface.

We would like to recall that in the collection of these data, the aspects of water as social and ecological asset were not taken into account. Therefore a much more complete analysis can be implemented when the design of the survey takes into account that perspective. On the contrary, the economic 'side' of water is better included in the design of the databases regarding water use, mainly in the NAMEA[8] frame.

For the purpose of the analysis, data is organized following figure 3 (above). We defined level n in this analysis by a spatial dimension and a political scope: the territory of the Catalan Autonomous Community. We will include the society living in this territory as well as

[8] National Accounting Matrix with Environmental Accounts, an accounting framework that adds Physical Satellite Accounts to the Input-Output Framework in monetary terms.

the economic activities performed in it[9] in one year, in concordance with available data. The levels over n (n+x) are determined by a spatial scale with natural scope that allow for the human system to access superficial, ground water and other water sources (would be n+1) and the water cycle that allows for the reservoirs to be fulfilled (n+x). Therefore these levels have a greater time scale, according to the timing of the flowing of the water throw the cycle and ecosystems. The upper graph of figure 3 represents the flows of water in relation to spatial analysis and in this way it can identify the fund natural reservoirs –such as rivers- that are relevant for the correct functioning of the ecosystem metabolism.

In the graph down the time scale is always a day, since all numbers refer to that time. The time lines given in the upper part represent the different time scales to which the processes happening at different levels are attached. The timeline at level n is a year, because all the data is collected for one year. This means that all numbers in the figures are related to the water need of the social funds in one year. Over level n, time scales are associated with the timings of the Water Cycle. In this level, water is a fund and therefore these times refer to the needed by water cycle to renew the amounts of water resource. At n-1, time refer to the social funds measured in Total Human Activity of the system (62 Gh). Each compartment has a wide which is proportional to the contribution to the THA. At level n-2, the time length is one day, and a different wide for each compartment of society refers to the differences in the working daily time in each of them. Agriculture is the compartment which, besides contributing less jobs and GDP per cubic meter, has longer working days.

In each of the levels, we can see the representation of the variable used as a fund (in level under n, this is human time) represented proportionally to their longitude. In the case of n-1, the human time allocated to consume good and services by the society is much larger than the time dedicated to produce them. At level n-2, the proportion of the day committed to different jobs per person is also different, with longer working time per day in agriculture. Also, the compartments showing the fund time for Paid Sector and the different sectors, are the transformers, where water (Blue Flows) is processed in order to produce GAV (Yellow flows). In doing so, characteristics of water are degraded, and a certain amount of water goes back to the upper levels (Dark blue). From the Total Water Throughput[10] (TWT) provided by Water Cycle and Ecosystems, 5,000 Hm^3 are available to Humans (TWA) in dams or rivers, from which 2639 Hm^3 are withdrawn as Human Appropriated water (HAW). The non withdrawn part (NAW), accounts for the rest.

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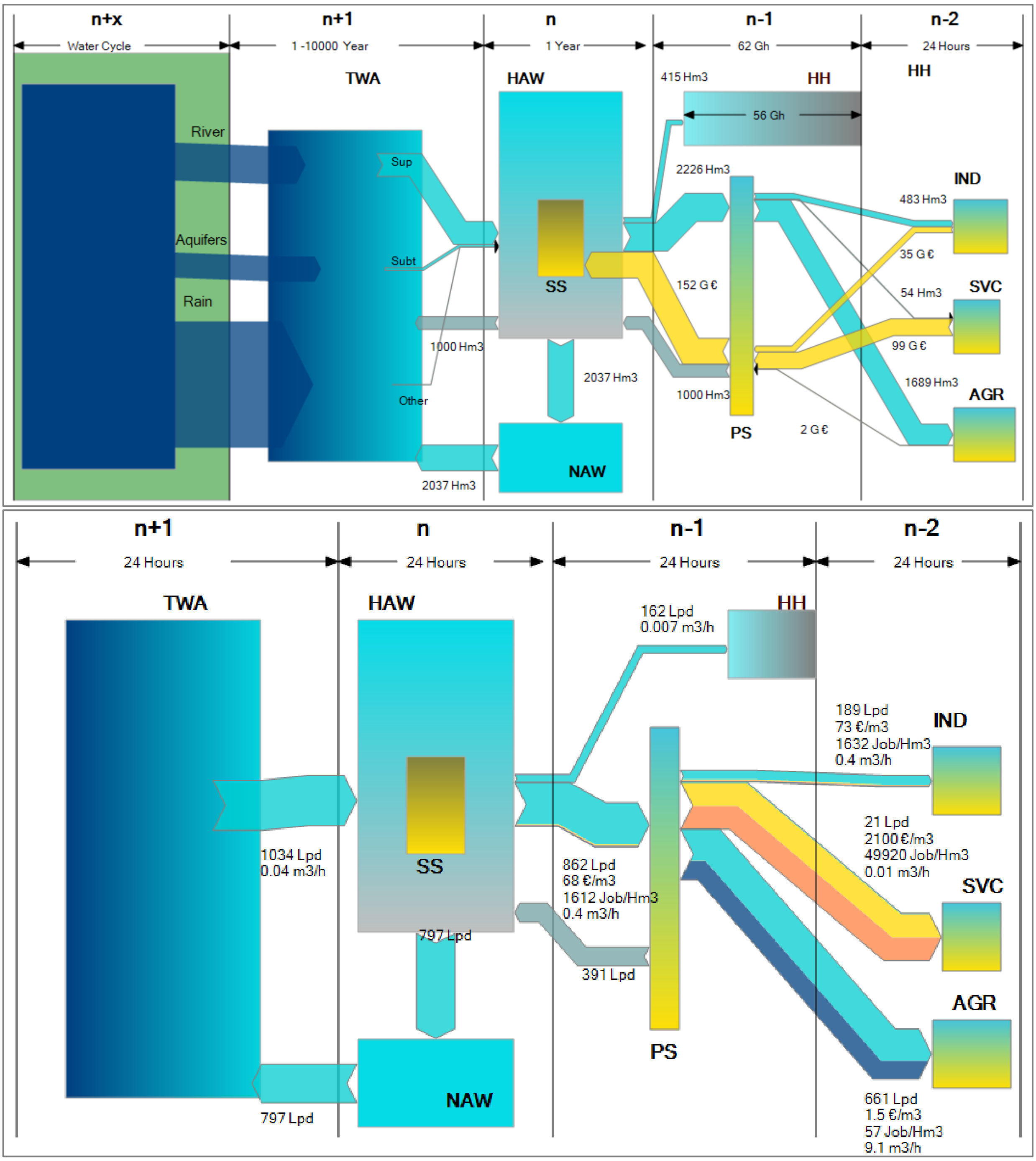
[9] In economic terms, we are taking into account the Gross Domestic Product and all the people living in Catalonia. If we would define a social scale, economic scope, we would take into account the Catalan society and therefore, economically would talk in terms of GNP.

[10] The numbers for TWT (20.000 Hm^3) and TWA (5000 Hm^3) are approximations. Due to the fact that it is not possible to measure the amount of rainfall and the flow of water between aquifers, the quantities are given to show the quantitative range of them. Depending on the methodology used to estimate these flows of water, the number might change considerably, mainly due to the equations for interpolation that are implemented in each procedure.

Figure 3. Description of the system in absolute (above) and relative (below) terms for the Study of the water use in Catalonia, 2005.



It is interesting to note that GVA flows with opposite direction to water. That is to show the contribution of the creation of GVA to the total of the Social System (SS) and the fact that the sectors use water to produce GAV. When comparing those flows in each of the sectors big asymmetries arise, especially in the case of Agriculture (AGR) and Services (SVC). Level n-3 opens the Agriculture level into crops and is not included in the picture for the sake of clarity.

The lower graph of Figure 3 represents the flows of water in relation to the use of water done in different categories of human activity. As Human Activity if a fund element in the society, the usefulness of water flows in the societal metabolism is given by the relevant attributes which characterize the flow. Here, the benchmarks of the water productivity are shown for comparability. The direct water use per person for the households in the lower graph of Figure 3 is 162 Lpd. The indicator of overall water use for the Catalan society is much higher, 1,034 Lpd. In fact, Catalans are not only using water directly (in the residential sector) but also in the rest of the economy. That is, in order to maintain their production and consumption patterns a much higher quantity of water is needed. This way the Catalan system is able to express the functions of the whole socio-economic system. Depending on whom do we impute the water use, the policies to control total consumption would dramatically change their focus. There are other works which describe the differences between these two perspectives, mainly developing an Input-Output analysis, but these do not include the qualitative aspect of the description of water that we develop here. For a good example on the imputation of emissions the reader can refer to (Serrano and Dietzenbacher, 2010).

The use of benchmarks to characterize the pace of water use at different hierarchical levels and in different compartments which express different functions makes it possible to outline a first scheme of how water is being used in modern societies. We can summarize this analysis in a very simple way: the majority of water is going to agriculture. The water used in agriculture is not effective in generating employment or added value, since both productivities of water are scandalously low if compared with the ones achieved by industry or services and government, especially regarding to labour.

4.2. The Catalan system in perspective

This work focuses on the lower levels (n-x) to explore the performance of the economic system regarding to water. We showed before the asymmetries of the flows of Water and GAV in some sectors. The fact is that this asymmetry is a pattern shared by other rich economies where agriculture represents a short percentage of the GDP.

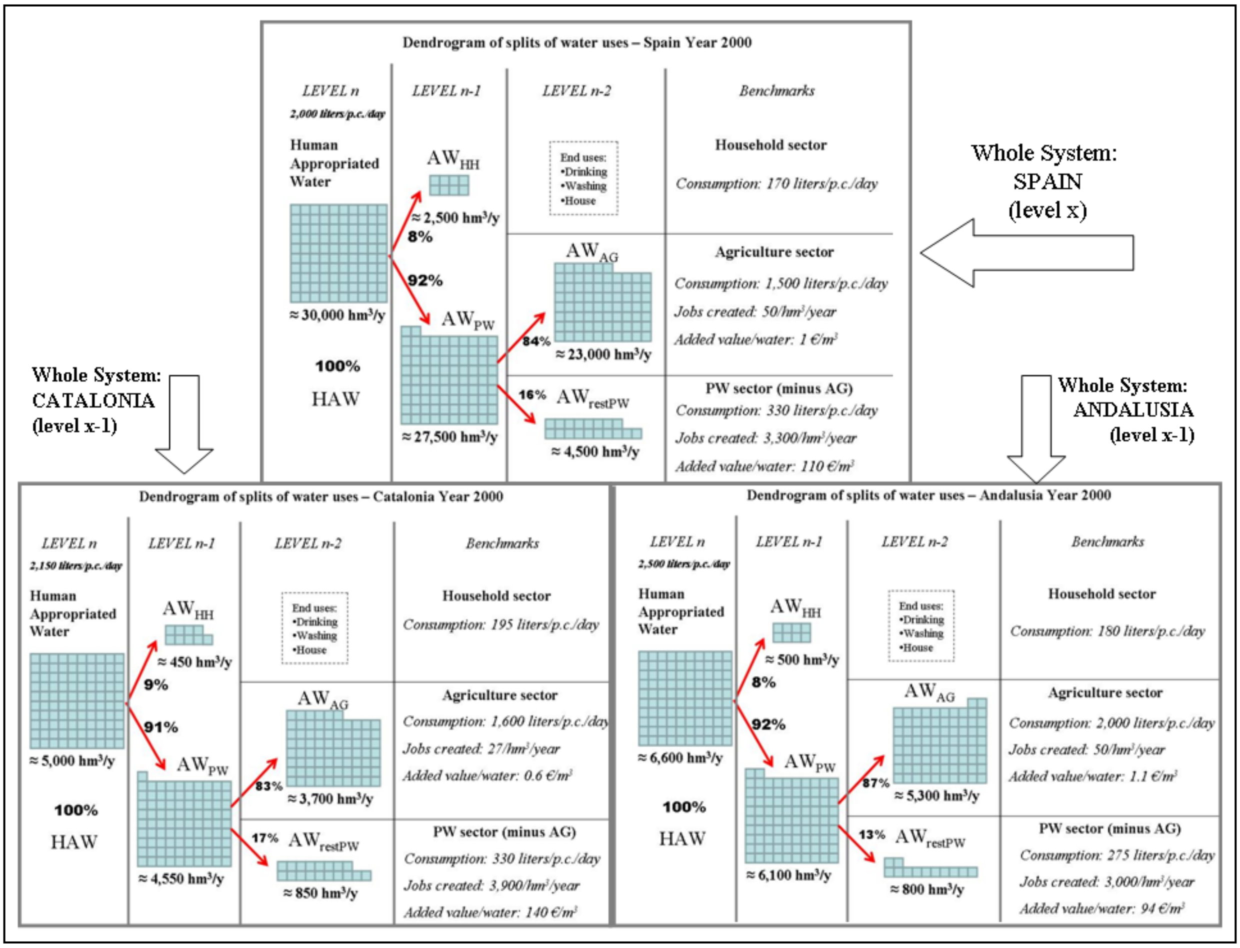
For the sake of comparison, Figure 4 shows the dendrogram of splits of two NUT-2 regions[11] -Catalonia and Andalusia- and the total of Spain (NUT-1) in 2000[12]. A dendrogram shows how to the total size of a fund e.g. hours of human activity – defined at a given level - splits into two smaller size compartments on the lower level (the hours of human activities in each one of the two lower level compartments), while preserving the overall size of the fund at each level. The figure gives some information on the benchmarks of the water use. The patterns of production and consumption are very similar in all of them. The paid work (PW) (Paid Sector-PS- before), needs much more water for its maintenance than the Households.

[11] Nomenclature of Territorial Units for Statistics

[12] The year 2000 was the latest we could obtain all data for all three regions. There are several important differences in the numbers for Catalonia, as a result of the drought suffered in the region in 2005.

As illustrated by the next split in the dendrogram this fact is due to the water us of Agriculture that represents more than 80% of the water use in PW.

Figure 4.   Comparative dendograms of Spain, Catalonia and Andalusia (2000)

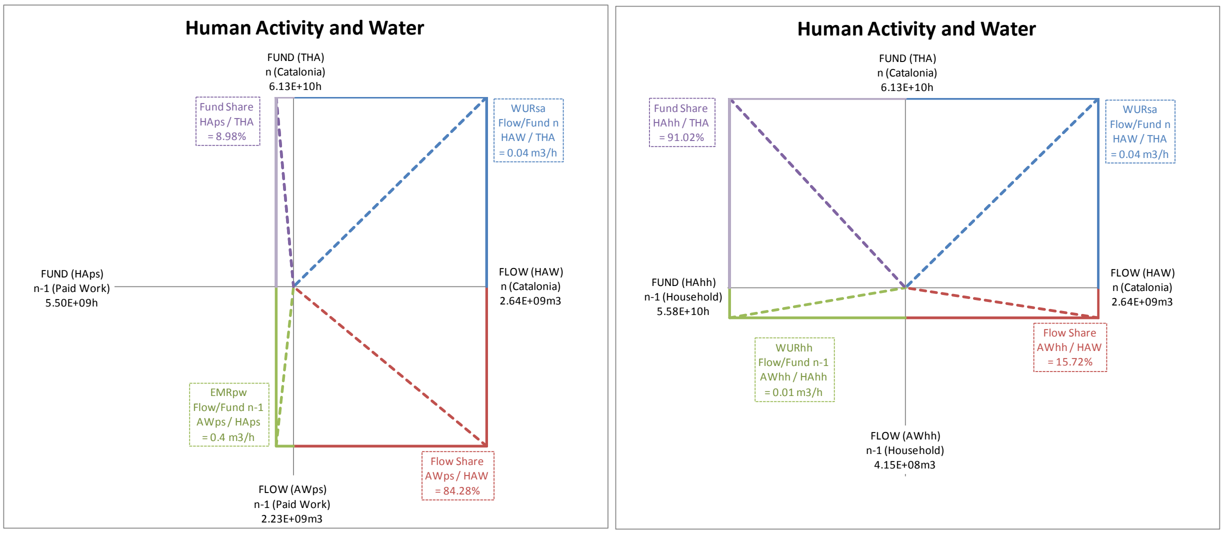


Traditional indicators of water use per person included only the water used directly by households as consumers (as for example the water used for bathing). This indicator sums up about 200 Lpd (Litres per person per day) in all three regions. When all the water used by the society is included, then it grows up ten times to 2,000 or 2,500 Lpd. This indicator is a much more valuable number when looking for an assessment of the overall needs of water by the social system. Even more important is the breakdown of this number in the specific use of water per capita per day required by society to express different functions. When we do so, we discover that, in rich economies with industrialized irrigation agriculture, the water use of this sector determines the bulk of water dependency of the society. In economies with a subsistence agriculture that is not irrigated, the appropriation of water as defined here (blue water) does not take place, since the water that plants extract from the soil is not accounted in the indicator of HAW.

4.3. *Metabolic Patterns of water use*

Following in the hierarchy, level n-1 represents the first split of the Catalan territory economy. Here production and consumption sides are separated and accounted as hours of time dedicated to work or consumption. Figure 5 examines the different responsibilities of consumers and producers in the use of water and links the consumption and the production perspective.

Figure 5. Bridging together water use for consumption(hh) and production(pw) in Catalonia (2005).

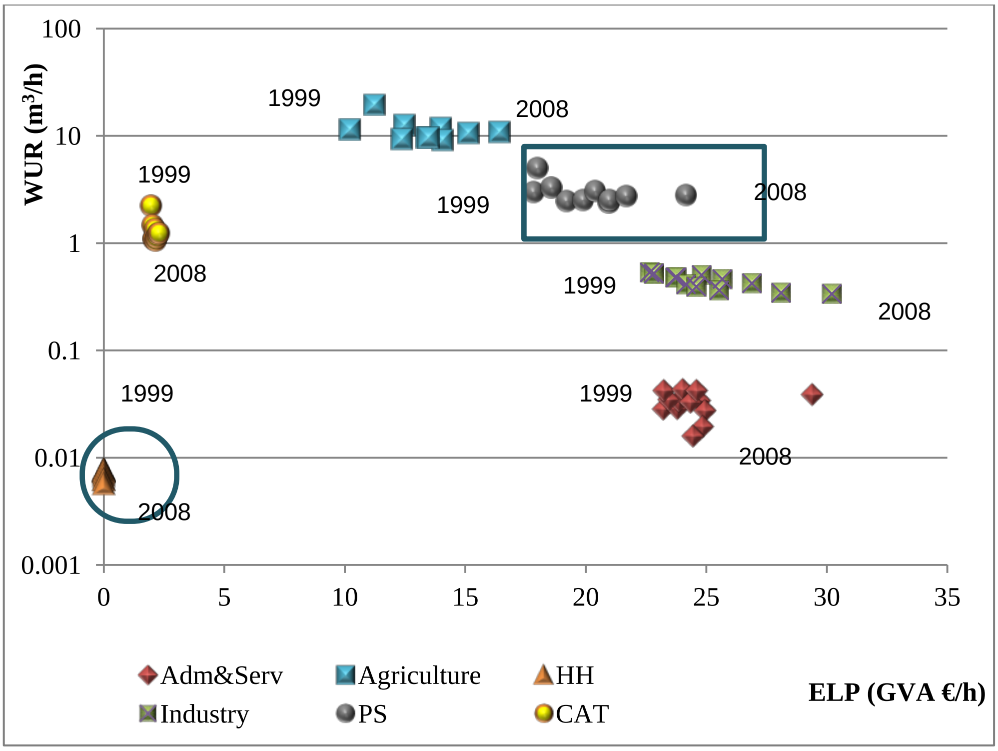


The Water Use Rate (WUR) of the society mentioned before (1,034 Lpd) can be translated into a Rate of about 40 litres of water used per hour (0.04 m^3/h). But as Households, Catalans consume "only" about 162 Lpd or 7 litres per hour (0.007 m^3/h). Traditional indicators consider only this number. The difference between the average consumption per person of the Catalan society and the average consumption per person of the households is explained by the intense consumption of water in the economic process. The other sectors of the economy need 400 litres per hour (0.4 m^3/h) in order to produce the goods and services they are consuming.

Some other studies have used this indirect perspective in the assessment of water use, including the estimation of the 'Water footprint' of countries (Hoekstra, 2009), which is similar to that of 'Ecological Footprint'. But those studies did not assess the metabolic patterns of the water use in terms of flow rate per hour, which can be used as benchmark to characterize and study typologies of human activities, and specific density of water use per hectare, which can be used as benchmark to characterize and study typologies of land uses.

When metabolic patterns are examined, the big differences between consumption and production regarding to the needs of water uses arise. Figure 6 shows the evolution of the production -inside the square- and consumption –inside the circle- patterns. We can recognize the sector is on the left side and on the bottom, since in the MuSIASEM system of accounting, the HH sector does not produce GAV. The position of the Average of the Society – at the level n – is also in the middle between the two, closer to the HH sector, because of the large difference in size (HA_{HH} >> HA_{PW}). In level n-2 something is different from the energy assessment completed until now: agriculture is the bigger consumer of water.

Figure 6. Production and consumption patterns in Catalonia (1999-2008)

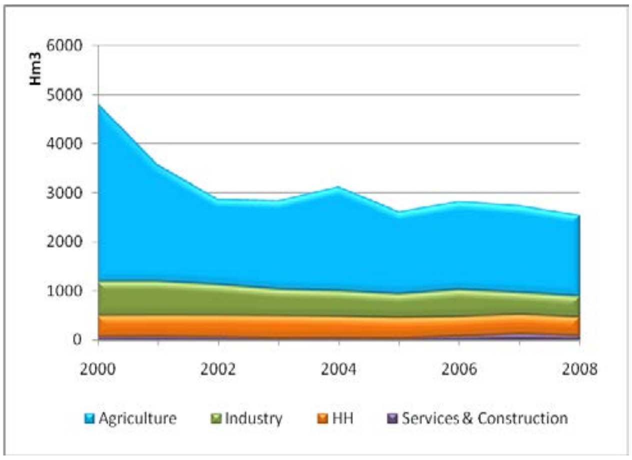


The evolution of water use shows a tendency to the decrease of WUR. Two reasons are important here. In one side, the changes of the legal framework in order to adapt to European regulations regarding water pricing and management (full cost recovery), mainly in industry. Second, and most important, is the shortage of water due to two important droughts. Figure 7 shows the evolution of total water use by different sectors (its HAW). Two valleys are clear in 2002-2003 and 2005. During the year 2005 precipitations were 36% shorter than the historical average in Spain. Droughts produced a diminution of the TWT since, by definition, they are situations in which the water provided by the natural cycle (rain, etc) is reduced.

The figure also shows how agriculture HAW is the less stable and changes the most when water is available or not. Therefore this sector is the most susceptible when shortages of water occur. The industrial sector decreases its water use gradually but it does not show the variation that agriculture does regarding to precipitation.

An interesting perspective is the comparison between the Catalan and a different economy, in this case the Andalusian. The Andalusian region is traditionally an agrarian region which came touristic in the last 30 years and has a lower GDP per capita than Catalonia, traditionally industrial. Figure 8 shows that all Andalusian sectors are displaced to the left with regards to the Catalan, except agriculture. The whole Paid Sectors (inside circle) are a good summary of the production in both regions. While the PS of Catalonia overtakes 20€/h in about the middle of the period, the Andalusian reaches the same level in 2008. In both cases, industry and services and administration are the motors of the economy.

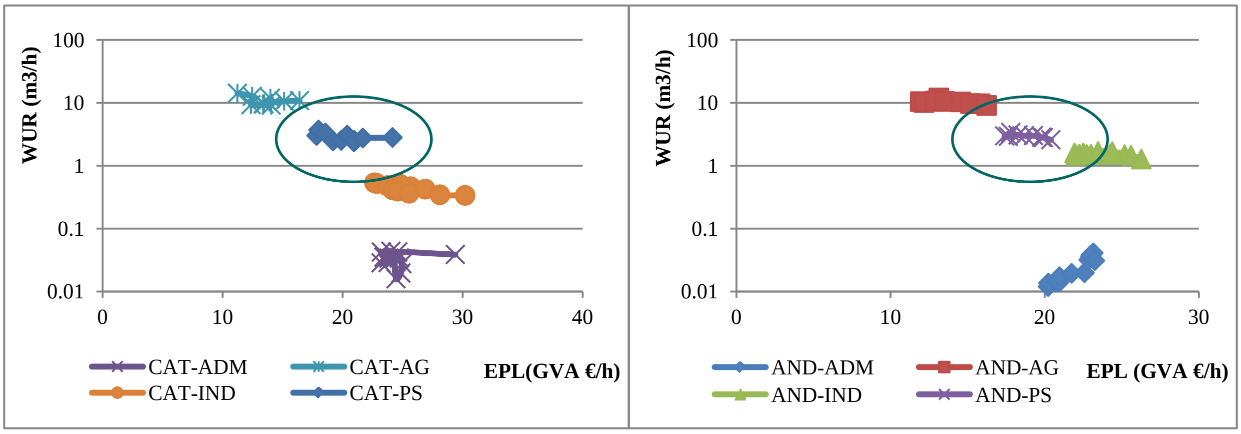
Figure 7. HAW by the Paid sectors and the households in Catalonia. (INE)



Regarding to water use, both PS are in the same range. The patterns are indeed quite similar except for the case of industry in Andalusia. Catalan better use of water shows technological improvements regarding to the Andalusian agriculture. The composition of the industry is also important: while in Catalonia there is a wide variety of industries, in Andalusia the main contributors to the industrial sector are mineral extractions and petrochemicals which does not allow for a great change in water use.

Regarding to Agriculture it is significant that both regions follow about the same patterns while different systems of production entails important differences in Economic Water Intensity, therefore in this case differences in the mix of agricultural production may have much more importance in determining the aggregated EWI than improvement in technology in production.

Figure 8. Comparison of the metabolic patterns of Catalonia and Andalusia (1999-2008)



In first place, Andalusia has a higher productivity of the land in average, mainly raised by the intensive production of the 'vegetable factories' in the south east. Also, the productivity of water in physical terms is one of the highest of Europe in these 'factories' due to the implementation of very modern irrigation technologies. Last, the economic productivities of water for fruits and vegetables and especially for strawberries coming from the west are very high because their destinations are the rich European markets. Catalan agriculture though is mainly dedicated to cereals and forage crops, although there is a significant production of fruits, it does not reach the intensive economic production of the 'vegetable factories' in the south east. Forage crops are important in the region.

Studying the sector agriculture beyond the level n-2 is essential if we aim at understanding not only the differences but the reasons of the large water consumption. However, going down at the level making possible to analyze differences among crops is complicated. In fact, while trustful estimations of the water consumed by each sector have been possible it is not possible to divide the fund time according to individual crops. Therefore, we have examined the compartment by estimating the Water Economic Intensity (WEI) – the results are given in table 5. In this way, we cannot generate a quantitative mechanism of scaling of the values across lower levels within the metabolic pattern, but it can help us to understand the way agriculture is working in the region. More specifically, how the characteristics of lower level elements affect the characteristics of elements defined at the higher level.

Table 4. Indicators of agriculture at level n-3: division by crop/livestock.

Crop Type	Water Economic Intensity (m^3/€ GAV)	Fraction of Water Use in Agriculture	Fraction of the total arable land	Fraction of total Catalunya	Contribution to Agriculture GAV	Contribution to Regional GAV
Rice	11,33	18,29	2,59	0,67	2,00	0,02
Fuits	1,73	22,54	16,56	4,30	19,67	0,24
Vegetables	0,36	2,63	1,94	0,50	9,00	0,11
Olive	2,41	4,11	14,24	3,70	2,11	0,03
Grapes	0,28	0,87	7,20	1,87	3,82	0,05
Flowers	0,12	0,46	0,08	0,02	4,73	0,06
Other crops	6,22	45,03	57,40	14,90	10,30	0,12
Livestock	0,06	1,64	-	-	48,37	0,58
TOTAL	-	-	-	-	-	1,20

As we mentioned, vegetable and fruits are not so important regarding to water economic intensity, since these kind of land is irrigated with newer technologies. Rice, in turn has a high WEI since it must be flooded during the most of the time of its growing period. The most of the water use (HAW) is for other crops which include cereals and forage crops, necessary for the feeding of the large cattle, especially pigs.

4.4. *Evolution of the patterns*

The evolution of the characteristics of the metabolic pattern illustrated in figure 7 shows that in general terms the water use in Catalonia is decreasing, mainly for the reduction of water use in agriculture (a reduction in size of the fund human activity allocated to this function), but also for the improvement of the water productivity in industry. How does this decrease influence the benchmarks presented in dendogram in Figure 3?

Table 5 shows the estimation of the benchmarks in year 2000 and 2005. There we observe that all the uses are smaller in 2005 due to the droughts. The main difference in this year is that agriculture used about 1000 Hm^3 less water in 2005. There are other reasons that influenced the benchmarks, besides the physical scarcity of water in the drought period. One of them is the increase of the population in Catalonia, and the occupation in the construction sector. From 1999 to 2008 the population grew in 700,000 people, mainly due to immigration. The life condition of immigrants is not easy and their consumption patterns are austere, thus they do not increase the average of the HAW but they do rise significantly the fund time.

Table 5. Comparison of Benchmarks in Catalonia

Benchmark	2000	2005
TOTAL-Use	1,714 Lpd	1,034 Lpd
HH-Use	191 Lpd	162 Lpd
AGR-Use	1,082 Lpd	661 Lpd
AGR-Jobs	36.7 Job/ Hm^3	57 Job/ Hm^3
AGR-GAV	0.8 €/m^3	1.5 €/m^3
PS-REST-Use	337 Lpd	210 Lpd
PS-REST-Jobs	3,629 Job/ Hm^3	6,504, Job/ Hm^3
PS-REST-GAV	128 €/m^3	278 €/m^3

5. Characterization of the metabolic patterns of water use to assess water policy: the case of Andarax river basin

To discuss about water management means dealing with the land colonisation pattern imposed by the political model of development implemented in each specific time frame (del Moral Ituarte, 2008). Put it in another way, the societal metabolic pattern of water in a territory depends on: (a) the existent land planning and economic policy, (b) the cultural perception of the value of water of the society; and (c) the biophysical availability of water in relation to external constraints (whether there is physical scarcity or not). If in an arid territory we implement a metabolic pattern characterized by an intensive water economy, it is very likely that this policy will lead to social scarcity (the societal demand will surpass water availability).

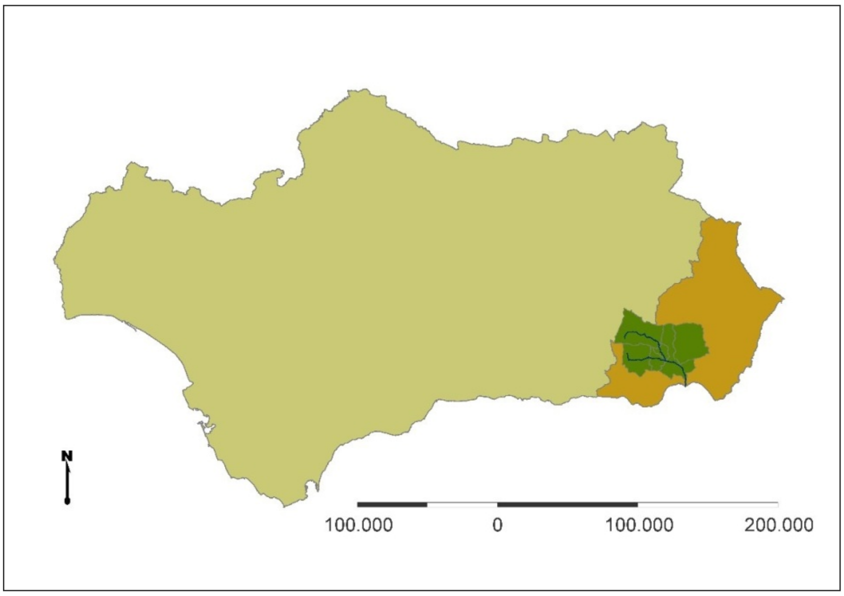
The *dynamic budget* (i.e. the required level of flows to maintain a specific size of funds) of water in a given territory is determined by: (i) the pace of extraction of water-flow for society on the demand side; and (ii) the requirements of water-fund for ecosystems on the supply side. The final size of the flow (both per hour and per hectare of colonized land) will depend on the combination of social, political, economical, cultural and biophysical features of each specific situation. As observed earlier, it is possible for a while to support excessive water consumption by damaging fund elements (e.g. overdrafting water from rivers or lakes) in the ecosystems. Albeit water management is a context-specific phenomenon (it is impredicative because water has a geographical reference) its problems go far beyond physical boundaries and span the globe, [politics] and history (Mollinga, 2008).

Analysing this inner relation water-territory implies moving in a natural scope at levels n+1, n+2 and n+3 of the posed framework in section 3.2, where river basin is the ecological systemic unit for water integrated management. In Europe, this was addressed by the Water Framework Directive 2000/60/CE (**WFD**) stating the achievement of the "good status" for all water bodies by 2015 by means of water demand management tools -defining a dynamic budget of water respecting the identity (integrity) of ecological funds. This change of perspective implies the establishment of a new paradigm turning from a demand satisfaction focus into an ecological priority one.

This brief case study is an application of the previous discussion on water metabolism at watershed level. We are in a very special moment in the Directive 2000 implementation in Spain since, after ten years, the new Watershed Management Plans (**WMP**) have been finally released. This fact generated future scenarios of water management for 2015 and 2027 according to the foreseen measures to retrieve the deteriorated ecological situation of water bodies. For this reason, this implementation can be considered as a very good opportunity to assess the current societal metabolism of water and the feasibility of the established measures to achieve the imposed objective. Using the MuSIASEM scheme, we can generate scenarios of water management and represent the resulting metabolic patterns at different scales in order to analyse their evolution in the watershed.

Almeria region is famous for its aridness (<200 mm of precipitation per year) and intensive greenhouse agriculture production of high water demanding crops. The total population in the watershed in 2009 was of 60,362 people in 39 rural municipalities, plus the city of Almeria with 188,810 inhabitants. Aquifers depletion has led to a serious engagement of the region economy, which agricultural sector has the highest GDPs of Andalusia (1,188 € in 2006 for the whole region of Almeria).

Figure 9. Map of Andalusia region, Almeria province in orange and the Andarax river basin in green



The second major water demand is the city of Almeria, which is supplied partially from the desalination plant and partially from the West-adjacent watershed aquifers, but a competence of water use with irrigation may emerge in the future. Reclaimed water from the wastewater treatment plant is transferred for irrigation to the East-adjacent watershed. It is thus important to consider not only the water balance inside the watershed but also the resulting interactions with inner territories. The evolution in the definition of "Available Water" in the river basin is a very good case of impredicativity. The increasing social scarcity has led to the consideration of other primary water sources as “available”, meaning that the valuation of characteristics necessary to consider water as a resource for both urban and agricultural uses has changed. This way, desalted water is currently a resource for urban uses as reclaimed water is for irrigation. Until now, irrigating with desalted water was forbidden, but the dramatic dwindling of water resource has driven a further change in the legislation (and thus in the value of characteristics required to constitute the resource).

In the following sections we show the potential of the MuSIASEM approach to a) represent and analyse metabolic patterns and b) build scenarios to assess public policies.

5.1. Representation of water metabolic pattern with the MuSIASEM scheme

Figure 10 shows the dendogram of splits in water use in Andarax River Basin for the year 2005. The splits are presented at:

Level *n+2*: **Available Water** from the different deemed sources in the watershed. With this specification, we aim a first attempt to approach the analysis water quality flows which will be continued in future works. In this case study, it is a very relevant assessment since scarcity in the Andarax is not only quantitative but qualitative. As observed, there is already a big share of alternative water sources (desalination and reclamation) which imply a technological boost in order to produce “available water” resource.

Level *n+1*: **Total Available Water** for human appropriation.

Level *n*: **Human Appropriated Water** (flows for societal metabolism). This value is indeed higher than the Total Available Water at n+1 due to aquifers overexploitation, i.e. damage of natural funds of water in the watershed.

Non Appropriated Water are the environmental flows (ecological funds) that should be accounted in the balance as outflows returning to the environment for ecosystems maintenance. This, while a compulsory measure in the WFD, is so far 0 in the Andarax. Determining what has been called as “Ecosystems Water Requirements” (Aylward et al. 2005) has become the bottleneck of the WMP in arid regions where surface water is practically dwindled every year and there is no previous reference to the “natural state of ecosystems”.

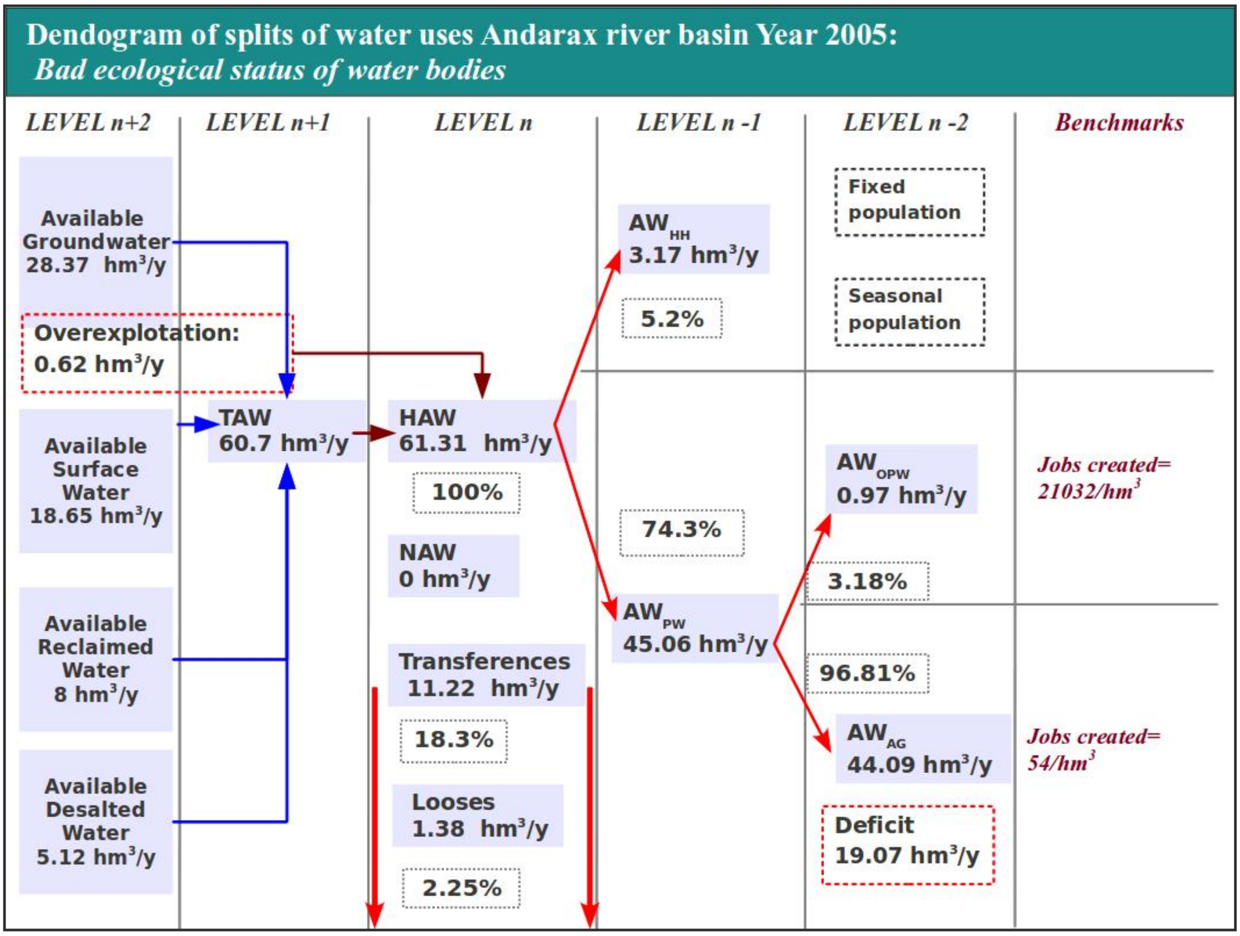
Transferences (18% of the HAW) split into 6.22 hm^3 of reclaimed wastewater for irrigation to the East-adjacent watershed and 5 hm^3 of desalted water to Almeria city. **Looses** in the supply system are represented at this level since there is not multilevel data. Both of them affect to the availability for rest of uses at lower levels.

Level *n-1*: Split between consumption (**Households**) and production (**Paid Work**) sides of the economy. As expected, the PW sector uses almost 75% of the HAW flow.

At level *n-2*, Split between **Agriculture** and **Other Productive Sectors**. It is clear the enormous weight of agriculture in the region, appropriating 96% of the water used in the whole

Paid Work sector and creating a higher rate of employment, 54 jobs/hm^3, than the mean in Andalusia showed in Table 5 (48 jobs/hm^3).

Figure 10. Overview of water metabolic pattern in Andarax river basin



The **Deficit** category is included in the WMP as escape via to justify the political commitment in Andalusia to not increase irrigated land. It is composed of two categories i) deficit due to a low Water Density regarding the optimum for the cultivated crops (Water Needs), stated now in 3921 m^3/ha and ii) deficit due to Colonised Land that is tagged as "irrigable" but not "irrigated" yet.

Obviously, this is still a reductionist approach since only one variable is included: Water quantity, extracted from natural funds and consumed as a flow in the societal metabolism of the watershed. Nonetheless, the multi-scale analysis allows having a clear overview of the water management strategy: *Where does the water come from and where does it go?* This is definitely not immediately acknowledged when looking at the data provided in the WMP without a significant knowledge of technical coefficients and calculations. Thus this kind of visualization can contribute to make the information accessible for public participation, which is one of the prerogatives of the WFD.

Once the water flows are analyzed in relation to the Time and Land budgets (the Water Flows are associated with a given profile of Fund elements), we can generate a complete series of indicators (flow/fund ratios) characteristic of the societal metabolism. These intensive variables are associated with the chosen taxonomy of activities described for the various compartments of the society and indicate specific rates of water uses at different scales. So far, we provide the Human Activity profile for 2005 as well as the Colonise Land for Agriculture in the watershed, generating Water Use Rate (AW/HA) and Water Density (AW/CL) indicators. As observed in the case study of Andalusia and Cataluña, more than 90% of Human Activity is devoted to consumption activities (on the Households side) while only 5% of the Appropriated Water goes to this subsystem. This generates a very low WUR in comparison to the Paid Work sector, accounting with 8% of the Human Activity and up to 75% of the water flows use.

Table 6. Indicators of water metabolic pattern in the Andarax watershed in 2005

		2005			Benchmark 2005	
		HA (M hr)	CI (ha)	HAW (hm^3)	WUR (l/h)	WD (m^3/ha)
n	Total Appropiated Water	468.62		61.30	130.80	
	Transfers	1591.71	1448	11.22	3.14	4295.58
	Looses			1.38		1.4
	Total Use Watershed	468.62		48.19	102.83	
n-1	Households (HH)	426.10		3.17	7.44	
n-1	Paid Work (PW)	42.52		45.02	1058.66	
n-2	Agriculture (AG)	4.44	11242	44.26	9962.36	3937.02
n-2	Other Productive Sectors (OPS)	38.08		1.28	33.61	

Once we have this picture of the metabolic pattern using extensive and intensive variables, we can build future scenarios on fund variables changes (different production/consumption patterns, depletion of natural funds, migrations, new land use planning, etc.) and check the resulting flows needed to maintain the new funds. In the next subsection we provide an application to the scenario of 2015 of “good ecological status” of the water bodies in the Andarax river basin.

5.2. Building scenarios with MuSIASEM

As mention, MuSIASEM allows for the generation and comparison of scenarios of plausible metabolic patterns, based on the relations of congruence among levels and compartments of the system. We have already proposed some indicators -intensive variables indicating ratios- that provide additional but useful information about *how and why the system is using the water flow.*

Let us now pose a scenario for 2015 using the MuSIASEM approach and make a comparison with the foreseen water management strategy by the administration. Taking as a base the Human Activity pattern existing in 2005, we propose an evolution on it quite “business as usual” in which:

- HA_{AG} is set according to the foreseen increase in cultivated land and the benchmark on HA_{AG} / CL_{AG} ; this is, maintaining the same rate of labour per hectare of cultivated land.
- HA_{OPS} is calculated using the same rate of working hours than in 2005 regarding the THA in the watershed.
- $HA_{PW} = HA_{AG} + HA_{OPS}$
- HA_{HH} is calculated according to a proportional increase of the THA.
- HA related to the Transfers is calculated according to the increase in population in Almeria city foreseen in the WPM.
- THA can be double checked by a) calculation according to the predicted demographic growth in the WMP= expected nº of people in 2015 x 365 days x 24 hrs; b) HA_{PW} + HA_{HH}; the difference among both is of 0,6 M hrs. Therefore, either the proportion of hours devoted to AG, to OPS or consumption in the HH sector are higher than in 2005. We will consider the HH hours increasing since it is more plausible due to the augmenting rate of unemployment in Spain.

Table 7. MuSIASEM scenario of water metabolic pattern in the Andarax watershed in 2015

		2015 – MuSIASEM			Benchmarcks 2015	
		HA (M hr)	Cl (has)	HAW (hm^3)	WUR (l/h)	WD (m^3/ha)
n	Total Appropiated Water	562.93		66.95	118.93	
	Transfers	1689.23	2005	13.91	**3.14**	**4295.58**
	Looses			1.4		
	Total Use Watershed	562.93		51.63	91.72	
n-1	Households (HH)	512.54		3.81	**7.44**	
n-1	Paid Work (PW)	50.39		47.82	948.97	
n-2	Agriculture (AG)	4.64	**11756**	46.28	**9962.36**	**3937.02**
n-2	Other Productive Sectors (OPS)	45.74		1.54	**33.61**	

Considering the foreseen increment on “irrigated” Colonised Land in the WMP and maintaining the benchmarks (flow/fund ratios) of Water Use (m^3/h) and Water Density (m^3/ha) of the different economic sectors at level n-2, we can calculate the associated Appropriated Water of Other Productive Sectors (OPS) and Agriculture (AG) required to sustain the new Time and Land budgets. Building bottom up, we can add this two obtaining HAW_{PW}. Then we can calculate the HAW_{HH} using the benchmark of WU_{HH} for 2005, finally obtaining the total HAW at level n. Results are shown in table 8, we mark in blue the benchmarks used to build the scenario.

What we find is that, considering the same metabolic rates for the economic sectors, when HA and CL increase, the overall metabolism of productive side slows down. This is shown in the decrease of 10% in the WUR_{PW}. The same pattern is observed at a higher *level n* in which the Total Appropriated Water increase until 66.9 hm^3 but the intensity of water use decreases. This would mean that the society in the watershed is more sustainable, because they are using water less intensively in order to maintain their fund identity. Emphasising again that this is a “business as usual” scenario that assumes that the population evolves as it has done in the last 10 years and that the water used per hectare does not change even if the irrigated land extends (i.e. the pattern of crops remains the same).

Table 8. WMP scenario in the Andarax watershed to achieve the WFD objectives in 2015

		2015 – Watershed Management Plan			Benchmarks 2015	
		HA (M hr)	CI (has)	HAW (hm^3)	WUR (l/h)	WD (m^3/ha)
n	Total Appropiated Water	562.93		**74.06**	**131.56**	
	Transfers	1689.23	2005	**14.79**	**3.97**	**4019.95**
	Looses			1.31		
	Total Use Watershed	562.93		**57.96**	**102.96**	
n-1	Households (HH)	512.54		3.96	7.72	
n-1	Paid Work (PW)	50.39		**54.00**	**1071.59**	
n-2	Agriculture (AG)	4.64	11756	**50.64**	**10900.06**	**4307.59**
n-2	Other Productive Sectors (OPS)	45.74		**3.36**	**73.45**	

Let us not compare this scenario with the planned strategy by the water administration in Andalusia, which should cope with the “good ecological status” of water bodies in 2015. We now show the Appropriated Water flows foreseen in the WPM and, basing on the same population growth (i.e same pattern of Human Activity) of the previous scenario, generate the benchmarks in the sake of comparison. We mark in red the greater differences with table 9 results.

While the MuSIASEM scenario appraised for an overall increase of 9% in the Human Appropriated Water regarding the 2005 situation, the WMP states up to 21%. Curiously, if the HAW at this level n in the MuSIASEM scenario is calculated basing on the benchmark of WUR 2005, a very similar result (73.6 hm^3 is obtained), indicating that this is probably an up-bottom built scenario. Analysing in this direction we can state several highlights:

- The Transfers are slightly higher here than in the MuSIASEM scenario because, as the proportional increase in CL is greater than population growth in Almeria, the resulting proportional contribution to the total Transferences changes. Nonetheless, the WMP foresees to maintain the brunt of Almeria city (increasing its WUR) and diminish the WD for irrigation. This means that people in the city are becoming less efficient in terms of water use (they are using more water per hour of Human Activity) while the irrigation area is increasing its efficiency (there are more has cultivated with less cubic meters). This land is planned for reconversion into drip irrigation. It is important to notice that WUR and WD here are benchmarks that qualify the water uses since the first does only account for the desalted water and the second for reclaimed wastewater.

- The Households sector scenario seems to coincide with what’s calculated with MuSIASEM, showing that this demand does conform to the Human Activity pattern.

- The PW sector does also increase its WUR since both subsectors are foreseen to be boosted as well:

    - OPS foresee a capital increment with the construction of a technological park. As it is supposed to create employment, the size of HA_{OPS} may change.

    - As expected, the greater increase is found in the agriculture sector, accounting for 4 hm^3 more than should do if the metabolic intensities are not changed. The main driver is the trap of the **Deficit** reduction which turns into i) an increase in the “irrigated land” because it’s being categorised it as “irrigable” in the Land Planning local plans (contradicting the regional political commitment to not extend irrigated surface); ii) an increase in the WD of previous and new CL due to a reconversion of the crops pattern from traditional low water demanding crops (tubercules, fruits, extensive crops) into greenhouse intensive, citrus and outside vegetables.

This comparative scenario does not seem to be a political bet to achieve the good ecological status of water bodies. Actually, aquifers overexploitation is only partially retrieved and, surprisingly, Non Appropriated Water for Environmental Flows is still considered 0, justifying the aquatic ecosystems as “very modified”.

Desalination and reclamation are foreseen as the alternative source to preserve the “status quo” (13.5 of Available Water from desalination and 16.6 from reclamation in 2015). Right now, the desalination plant of Almeria city is working at 20% of capacity. Curiously, in the WMP there is no prevention of the energetic costs that such a technological boost will suppose and how water price would thus rise. This is a very delicate problem in Spain where there is a deep cultural believe on water as a renewable free resource and the full costs recovery principle of the WFD is not welcome among population. This integrated analysis can be made with MuSIASEM, assessing the energetic and economical constraints for the planned water budget. Notice that this budget changes from 2005 to 2015 not only quantitatively but also qualitatively, meaning that both the sources of water and the set of end uses (and relative profile in the mix) vary.

Improvement of irrigation systems efficiency is foreseen as the main water demand control device. An investment will be made to increase this efficiency from 71% to 84%. This increase does not translate into a saving of water or environmental flow but in the extension of the Colonised Land for Agriculture and of high water demanding crops, thus of Human Appropriated Water. As in the Jevon's Paradox, increase technologies efficiency does not mean a reduction in the total consumption of the resource but usually the opposite. Finally, it is obvious that the main driver of water metabolism is the crop pattern, since it is the one determining the Water Density.

5.3. Brief Conclusions

As learned from previous applications of societal metabolism, the combination of extensive variables (indicating the size of the flows) and intensive variables (the ratio of water flow per unit of fund element) builds up redundancy in the information space, increasing the robustness of the analysis (Giampietro et al 2011). The analysis of the different crops and land use patterns at n-3 and n-4 levels and related water flows can provide insights about water metabolism drivers.

Regarding the management of water sources in relation to: (i) the possibility of overexploitation and relative impact on ecosystems (water as a fund); and (ii) the energetic costs of new alternative water sources (reclamation and desalination), it is possible to use the MuSIASEM approach to run robust scenarios and generate integrated set of indicators of performance.

It should be noted that the quantitative relation between “the quantity of water” that should be left as ecological fund before affecting in negative way the health of ecosystems is still unclear. For example, it is not easy to determine a direct causal relation among a certain reduction of the water flow in a river and the relative effect on biodiversity. However, through the category Ecosystems Water Requirements the MuSIASEM approach can be used to set indicators (water-flow/water-fund) explicitly addressing the existence of relation between the performance of societal water metabolism and the performance of ecological water metabolism. In particular, the MuSIASEM approach makes it possible to link this type of analysis to an economic dimension of the metabolic pattern of water in terms of Gross Added Value per hectare of land use and Economic Labour Productivity (per hour of human activity) in which the Water Supply Costs can be inserted as a relevant factor.

We can end this section on possible policy applications of the MuSIASEM approach by saying that it seems to be a very promising approach for water management strategies analysis at watershed level. This method can address the epistemological challenge of the unavoidable existence of many non-equivalent descriptive domains in water analysis (scientific representations based on different scales and dimensions of analysis) that so far proved to be difficult to integrate. A clear limitation for this type of analysis is represented by the lack of disaggregated data on: (a) Time Use in the Paid Work sector (especially when going into different economic sectors); and (b) Economic Variables in relation to the existence of Virtual Water transfers among productions taking place in different economies.

6. Conclusions

In this paper we explore the complexity of quantitative analysis of water use in relation to the issue of sustainability. In fact, the flows of water in our planet represent a complex reality which can be studied using many different perceptions and narratives referring to different scales and dimensions of analysis. For this reason, a quantitative analysis to be used to study the sustainability of these flows has to be based on analytical methods that are semantically open: they must be able to define what we mean with the term “water” when crossing different scales of analysis. These different useful perceptions have to be chosen ‘a la carte’ depending on the goal of the study and the resulting relevant narrative about “water”.

By adopting the rationale proposed by Georgescu-Roegen’s Flow/Fund model of production, we proposed to define water mainly as a flow element (typologies of water uses) when considering the metabolic pattern of water within socio-economic systems and mainly as a fund element (structural/functional compartments) when considering the metabolic pattern of water within ecosystems. After having adopted this definition we can say that the identity of the fund elements defined in the ecosystems embedding the society determine the severity of external constraint affecting the supply of water flows to social systems. At a larger scale, we can define another typology of fund element in relation to the metabolic pattern of water of the Earth: the Water Cycle, which should be considered as “the fund element” par excellence on Earth, since it regularizes life, preserving the peculiar identity of our planet – frequently called “the Blue planet”. In this paper we claimed that, in order to understand the Water Metabolism, one has to adopt a multi-level approach able to deal with the connections between Societal, Ecosystem and Earth Water Metabolism. Therefore, water must become a key flow considered in biophysical analysis of Societal Metabolism which has to be assessed across different scales, since water flows within the water cycle are a global scaling factor within the process of self-organization taking place on the Earth.

The MuSIASEM method requires a semantic categorization of water based on the attributes relevant for the study. Due to the multi-functionality of water which plays different roles (e.g. both flow and fund) in different compartments defined at different scales, the definition of a grammar for a multi-scale accounting requires a semantic tailoring on the specificity of the problem. That is, beside its quantity, water has to be described using a pertinent set of attributes that reflects the relevant functions it performs within the chosen analysis (drinkability, potential energy carrier, mother). All these attributes are related to the possibility of providing benefits to humans and ecosystems. We used the Ecosystem Service narrative to categorize benefits for social systems (services provided by water), and benefits for ecosystems (functions). Since water becomes a resource when it can be used for a concrete purpose, it is precisely the attributes, that is the ability to provide services and functions which make water a resource. Therefore, the loss of a relevant attribute can be associated with the consumption of water resource. In this case, we are dealing with a water use – water is a flow element. When the original relevant attributes are preserved the water refers to a fund element.

Regarding MuSIASEM, the choice of the taxonomy of categories that will be used to build a quantitative characterization, if explicitly discussed as a mandatory step of the accounting procedure, forces the analyst to deal with the qualitative side of the analysis. For example, when dealing with food intake we can talk of “grams of protein supply” but then, when generating this information for a Muslim or a Jew, it becomes crucial to specify whether these proteins come from pork. In the same way, when dealing with the supply of 1 cubic meter of water, depending on the use to be done with it, it is essential to consider a set of relevant attributes associated with the specific water use defined by the users of the analysis . By doing so, it becomes possible to provide a qualitative dimension to the resulting quantitative characterization even when choosing a finite set of attributes to be used in the analysis.

In the analysis of water metabolism we adopted the same fund definitions typical of the MuSIASEM approach (human activity – to calculate rate per hour – and colonised land – to calculate density per hectare). Then starting from the focal level (level n) as the social system we define the interface of the human and natural system across the level n/level n+1. When crossing this line the accounting of water switches from “ecological fund” (level n+1/n) to a “social flow” (level n/n-1). Levels above the social level (n+x) would be those reservoirs, ecosystems and parts of the water cycle that stabilize water availability at level n. In such levels water maintains the structural and functional compartments of ecosystems, and can be considered as a fund. Levels below the whole society level (n-x) are those where water is used by humans for local tasks. At these levels water uses are considered a flow which crosses the boundary of the social system under analysis and are transformed.

The comparison carried out in the case studies raised our awareness about the importance of considering an appropriate scale. Our preliminary analysis shows that it is possible to define metabolic characteristics for elements defined at local scales (either natural or social) and the bridging of the characteristics of different “compartments” of the water cycle in ecological levels. The quantitative results provide useful information which is relevant for policy discussion. In spite of that, there is a systemic lack of data for activities that are not relatively important in terms of economic value – e.g. for agricultural activities – even though they are very relevant for the consumption of water. A case in point is the lack of the disaggregation of information of jobs per crops noted in level n-3 in Catalonia, a lack of information due to the negligible contribution that the agricultural sector has in terms of its share of the total GDP and labour.

The MuSIASEM approach seems to be particularly effective in comparison. In fact, even comparing social systems of different dimensions (e.g. Catalonia versus Spain) when comparing intensive variables of analogous sectors (e.g. water per hour in agriculture, or water per € in the service sector) we can compare “apples” with “apples” and “oranges” with “oranges” also when dealing with systems quite different. In the same way the WUR of Andalusia is similar to that of Catalonia while their EPL is different in some sectors and similar in other sectors. After having individuated both differences and similarities, we can open compartments and explaining their behaviour and their constraints by looking at the characteristics lower level elements. In this way differences and similarities can be explained in terms of: (i) different characteristics of the set of lower level economic activities; (ii) different mix of economic activities at the lower level; (iii) a combination of the previous two points.

After having gathered the information across scales we can make scenarios by imagining different combination of extensive and intensive variables in the definition of “what is the system” and “what will do”. For example, the share of HAW by Households is higher in the Andarax River than in Catalonia, mainly due to the fact that agriculture in that region is highly developed technologically and therefore uses less water in quantitative terms. But also changes in population density, in the mix of economic activities or in the technical coefficients can be incorporated to check the differences that these possible changes can generate at a certain level in order to compare the aggregate demand with the definition of external constraints provided by the available fund element in ecological systems.

In the two case studies we used data coming from different scales: from the Andarax River Basin Authority and from the Spanish National Institute. It is important to be able to deal and process data coming from different type of sources and referring to different scales, since the Water Framework Directive states that the proper management unit for water is the River Basin, however, not necessarily, the River Basin scale is the best scale to study relevant attributes and characteristics of the metabolic pattern of water across different levels.

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