Water-use in rural systems and the incoherence of water and agricultural policies in Europe: The case of Andarax river basin

Abstract:

Water is a relevant resource for rural systems which is complex in multiple ways. This paper has a double aim: to propose a specific method to include water as a variable in rural systems studies with the Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism approach and to show the usefulness of this method for the assessment of the implementation of different policies driving rural change in Europe. For these purposes, the river basin scale is chosen, since it is the socio-ecological systemic unit for water management established in the Water Framework Directive 2000/60/CE. Based on the water metabolism approach, a multi-scale water-use account is provided for a Mediterranean river basin in Andalusia, integrating water cycle, ecosystems and social levels. Particularly focusing on agricultural production, a relevant set of indicators is proposed in order to analyse internal (economic, institutional) and external (biophysical) constraints shaping different metabolic patterns. Finally, the integration of water and agricultural planning is assessed in terms of biophysical feasibility of the new metabolic patterns generated by the scenarios posed in these policies. While on a European level water policy is ambitious in terms of ecological conservation, the entanglement of multiple scales of political and economic organization with the diversity of local new ruralities blurs these priorities in a rather slow transition to a new water culture.

Keywords:

Socio-ecological water metabolism; water-use sustainability; river basin management; Water Framework Directive, policy integration, Almeria

Jel codes:

Q13; Q15; Q18; Q25; Q57

1 Introduction

Land use and water use are inherently related. The presence of water is one of the main biophysical constraints for land use management, especially regarding the lack of water and the agricultural activity. In arid regions, the history of agricultural change is connected to the evolution of water grabbing (Sanchez Ramos 2010) and the improvement of the social strategies of adaptation to drought. Water ecosystems have thus evolved with social systems by means of the most ingenious hydraulic infrastructures to attend the intensification of agriculture.

Among the most important changes in the water-use pattern brought by process is the increasing dependency of irrigation on blue water to the detriment of green water from the rain[1]. The consequences of this change should not be neglected in a sound integrated water and land use management (Willaarts et al., 2012). While green water is still mainly silent, blue water is frequently perceived as a renewable and unlimited resource whose appropriation is limited by technological and infrastructural factors only (Madrid, 2006; Moyano 2006). In the assessment of water use, little attention has been paid to the complexity of water dynamics and its function as link between social and ecological systems (Madrid and Cabello, 2011[2]). In order to deal with this lack, Madrid et al., 2013 propose to jointly assess the *Societal and Ecological Metabolism of Water* with MuSIASEM (Giampietro et al., 2009) as a way to integrate the social dynamics of water use with the impacts created in water bodies.

The work presented here is an application of this rationale at river basin scale. River basin has been chosen as it combines the biophysical reference of the water cycle and the institutional settings for its management, enabling the connection of the societal and the ecosystem analyses. The main problem entailed by this scale of representation is the mismatch between water and non-water related policies: agriculture, land planning, trade, tourism and urbanism have other management extents. The debate about the appropriateness of transforming river basins *from a technical unit to a governance tool* is recently gaining importance (Cohen and Davison, 2011; Suhardiman et al. 2012), especially after the Blueprint Impacts Assessment of the EU recognised policy integration as one of the mayor challenges in water management[3].

In this work, we i) develop a specific method to include water as a variable in rural systems studies with the Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism (MuSIASEM) and ii) apply it to assess the implementation of different policies affecting rural change. The paper is organised as follows. In section 2, we analyse the political and institutional framework in our study area alongside the central theme of this special issue: driving forces of rural change and how new ruralities emerge. In section 3 we make a brief description of the concept of Water Metabolism and

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[1] Green and blue water concepts (Falkenmark, 1995) were developed to differentiate that part of rain that remains in the soil and feeds plants for Net Primary Productivity from the one that runs directly into surface and ground water bodies. It is blue water the one appropriated directly for human consumption, even though green water use in crops production is even higher.

[2] Re-opening the black box in societal metabolism: the application of MuSIASEM to water. http://www.recercat.cat//handle/2072/172087

[3] A blueprint to Safeguard Europe's Water resources - Communication from the Commission (COM(2012)673.

describe the methods applied in this paper. Section 4 is devoted to the analytical part and result discussion while Section 5 contains the conclusions.

2 Rural change and water-use: institutional settings

European rurality is an exemplary outcome of the permanent debate and tension among the multi-level forces of rural change. The World Trade Organization and the Doha Round push the elimination of trade-distorting subsidies coupled to agricultural production at global level (Potter and Lobley, 2004). At national levels, big farmers' organizations maintain a neomercantilist discourse of state-protectionism of production (Potter and Tilzey, 2007). In between, the European Union (EU) acts as institutional mediator. The awareness of the environmental damaging effects of agriculture and of food safety fosters the expansion of ecological tagging and tracking mechanisms over local food production chains. The discourse of multifunctionality (Losch, 2004), emerging from the industrial agriculture crisis, provides a strategic opening in which to recognize the social and ecological landscape functions of agriculture and rural settlement (Hollander, 2004). Noticeably, these discourses are not evenly distributed along the European territory, yet respond to national (and local) historic, social and political contexts.

The result of these co-existing strains is reflected in the continuous agriculture restructuring processes through the Common Agricultural Policy (CAP) reforms. The latest (2003, 2008 "Health check") and upcoming 2014 maintain a patent twofold stake: promotion of an agro-industrial competitive model through the Direct Payments[4] while, at the same time, green and rural development subsidies are incorporated to the CAP scope. The very relevant consequences are gathered by McMichael (2011): On the one hand, Direct Payments allow prices to be lowered below production costs in order to seek for competitiveness. On the other hand, greening and rural development funds allow the institutionalization of multifunctionality as an environmental and social form of governance that remains within market calculations, maintaining the reductionism to the monetary dimension.

With this socio-political frame in the agricultural institutions, the Water Framework Directive[5] (WFD) arises as a revolutionary policy in environmental terms because it states the achievement of the "good ecological status" for all water bodies. This implies shifting the political priority from the demand satisfaction to the ecosystems recovery and conservation. It is the first EU directive including mandatory public participation and demanding a compulsory economic analysis of water use that includes environmental and resource costs[6]. To that end, it establishes the river basin as the management unit.

While at European scale this brought an important institutional reconfiguration (Kaika 2003), in Spain the river basin has been the traditional water management scale since the nineteenth century. Nevertheless, WFD implementation requires waiving a deeply rooted *Old Water Culture*

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[4] Direct Payments are lump sums to farmers decoupled from production.

[5] Directive 2000/60/CE.

[6] Environmental costs: cost of the required measures for ecosystems status deterioration prevention, mitigation and restoration; Resource costs: opportunity costs for water users when the resource is dwindled over its natural recovery capacity.

also known as the *Old Water Management* paradigm (Swyngedouw 1999, Aguilera 2008, Moral 2009) which focused essentially on water supply security. New inclusive and deliberative modes of governance are now demanded (Moss and Newig, 2010) that integrate water environmental and social systems, basing on the principles of the *New Water Culture*: efficiency, rationality and sustainability (Del Moral, 2006; Moyano and Garrido 2009).

The semi-federal architecture of the Spanish administration anticipates a troubled down-scaling from European to local policies since, in many cases, water, rural and agriculture plans are managed at different institutional levels. Table 1 contains a compilation of the main characteristics of their enforcement in Andalusia.

[TABLE 1 ABOUT HERE]

At the regional level, the AIA addresses the main current challenges of Andalusia agriculture, including the implementation of the WFD. Some contradictions between the lines of the CAP and the WFD are observed in its proposals. For example, no increment of the total irrigable area -land with installed irrigation infrastructure- is foreseen, even though the total irrigated area -actually irrigated land- will be incremented in about 70,000 hectares to match the former. This situation presents itself as complicated since, up to date, the reason why not all the irrigable area is being exploited is the lack of available water.

The core strategy of the AIA to overcome this problem is a *modernization* of agricultural areas which would achieve i) sustainability in the use of water ii) raise the employment and iii) increase land productivity. This win-win scenario would be reached through i) public investment on more efficient drip irrigation technology, ii) investment on new water primary sources such as reclamation and desalination iii) farmers technical support and education. In addition, crop pattern change is promoted *from low economically productive and high water consumptive to highly productive and/or low water consumer crops* (CAP 2009 pp. 30-31)[7]. These initiatives are 65-85% funded by the APRD’s Axes 1: Improvement of infrastructures of agricultural exploitations (pp. 70-80). On the other hand, little funds are left for Axes 2 and 3, which include compensations for DMA implementation, agroecological programmes, hydro-forestry restoration or wastewater treatment (Moyano and Garrido 2009).

The MRBMPs is the water management strategy to adapt local policies to the WFD. It affects the internal river basins of Andalusia which drain to the Mediterranean Sea and includes a set of measures to retrieve the good ecological status of water bodies and ensuing scenarios of water use for 2015 and 2027. These scenarios present themselves as challenging, because they have to integrate expectations of new water uses with the full-costs recovery of the water supply and the ecological requirements of water. Clearly, scenarios of agricultural land use must be coordinated in this effort.

2.1 The Andarax river basin as complex hybrid of ruralities

Andalusia is a region in the South of Spain with warm Mediterranean climate (mean temperature

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[7] Consejería de Agricultura y Pesca. 2009. Impact of the Water Framework Directive and the Common Agricultural Policy on irrigated agriculture in Andalusia.

around 16ºC) and periodic droughts. It is a traditionally agricultural area with a developed agro-industry. Intensive agriculture is mostly devoted to high water-demand crops, particularly vegetables and olive groves. It covers 32% of agricultural land, generating 63% of final agrarian production and 63% of its employment[8]. This production system has been publicly promoted (total surface has increased in 55% since 80's), even though water availability is a clear biophysical constraint to its sustainability. According to the last Andalusia Development and Territorial Report (Pita and Pedregal, 2011, pp. 155), the promotion of an "innovation economy" within global food and tourism markets has driven Andalusia farming systems into a functional specialization in three lines: economic-productive, economic-social and environmental-territorial. First, there is a shift towards intensive agro-industries or high-quality product industries that are able to compete for high monetary profits in the global market. Second, there is a proliferation of low productive and highly CAP-subsidized systems associated to jobs creation, diversification of activities and fight against rural exodus. Third, in ecological and traditional agriculture systems of mountain and protected areas, low benefits are compensated by other activities related to the provision of cultural and environmental services.

Almeria is one of the 8-large provinces of Andalusia. It has a long history of episodes of economic specialization associated to demographic "booms" and severe environmental disturbances (Latorre et al., 2001). Intensive mining until XIX century drove extended deforestation, shaping most of the current dry landscape. With its semiarid conditions (200-500 mm/year), the region is renowned for being the major European exporter of greenhouse vegetables to Europe. Inherited from the agrarian reform of the 1939-1965 dictatorship, intensive production of Almeria constitutes a paradigmatic example of techno-agroecosystem as highly sophisticated technology is continuously incorporated to increase productivity and retrieve environmental damage. From 1960s, it has brought about in the formerly very poor coastal area a flourishing economy together with an intense worker-immigration to compensate low local population, sadly culminating in some episodes of social conflicts between different cultures (Contreras, 2002). Depletion of aquifers has led to a serious struggle of the regional economy, where agricultural sector constitutes 11% of the GDP (the highest proportion of all provinces in Spain). Desalination and reuse are foreseen as the alternative source to preserve aquifers, albeit that the existent plants are unable to operate at full efficiency due to the relatively high price of desalinated water. The widespread reputation as "vegetable factory" (Delgado, 2006) veils the great social and ecological diversity of the region.

This study is conducted in the Andarax river basin. One of the main rivers of the region, the Andarax flows along 67 km from the highest Spanish peaks in Sierra Nevada National Park (3.478 mts) into the Mediterranean sea in Almeria city. The basin occupies around 25% of the province, with a total population of 60,362 people in 39 rural municipalities. Almeria city accounts for 188,810 inhabitants and it represents the second highest water demand in the Andarax. Rural-urban dynamics play an essential role in shaping the spatial segregation of economic activities and

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[8] Andalusia Irrigation Agenda. Horizon 2015. Page 4.

agricultural production modes. But not least is the influence of the sharp climatic and environmental gradient from North-East to South-West. As a result, the Andarax basin contains a myriad of ecological, cultural and economic peculiarities conforming to an interesting hybrid rurality “between the social and the natural, the human and the non-human, the rural and the non-rural and the local and the global” (Murdoch 2003, quoted in Woods 2007: 495).

[FIGURE 1 ABOUT HERE]

As observed in Figure 1, agricultural areas do not coincide with watersheds limits. *Alto y Medio Andarax, Guadix* and *Nacimiento* are located in mountain areas with small rural villages and a cultural legacy from the Muslim period in terms of architecture, agriculture and water management (Sanchez Ramos 2010). Diametrically opposed, *Bajo Andarax* is the area surrounding Almeria city, with larger towns and higher incomes per capita. *Tabernas* is a film-set natural protected desert with a characteristic pictorial landscape. The picture gets even more complicated if we add rural development areas or municipalities, giving an idea of the multiple administrations (and spatial extents) involved in water related decision-making.

3 Method: Multi-Scale Integrated Analysis of Water Metabolism

3.1 Introduction to water metabolism

Water has multiple levels of complexity of which its suitable definition and scales of analysis are the most important. It is not only a provider of services to social and eco-systems but also acts as a link between them. Our conceptualization of water-use does not refer to the consumption of a given quantity of the chemical element water *but to the exploitation of services that a given volume of water provides.* This definition follows the logic of the concept of the metabolism of societies (Fischer-Kowalski, 1998; Swyngedouw, 2006; Giampietro et al., 2011) but adds the discourse of the use of hydrological ecosystem services (Aylward et al, 2005; Brauman et al., 2007). When inserted in MuSIASEM, this definition of water allows the analysis of water-use in an integrated manner (Madrid et al 2013). MuSIASEM is specifically designed to deal with the complexity of sustainability in hierarchical systems, such as river basins.

In MuSIASEM, water is given a semantically open classification as a flow or a fund, following the concepts of Georgescu-Roegen (1971). Usually, *societal uses* of water fall in the category of *flow*, since it is *transformed* in order to maintain social functions and create economic value. At the same time, it can have the role of *fund for ecosystems*, because the pattern of water availability *remains* along their functional scales, which are much broader than societal ones, and because water can be used to define the identity[9] of ecosystems.

The metabolic pattern of water in a given territory is determined by (i) the pace of extraction of water flows for society on the demand side, and (ii) the capacity of water funds on ecosystems levels to provide those flows on the supply side. The final size of the societal flows will depend on

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[9] Identity: defined as each of the researcher’s perceptions of the investigated system as an entity (or individuality) distinct from its background and from other systems with which it is interacting (Giampietro 2004).

the combination of social, political, economic, cultural and biophysical features of each specific situation. Albeit water management is a territory-specific phenomenon, its problems go far beyond physical boundaries and span the globe, politics and history (Mollinga 2008). The perspective of the researcher and the relevant end uses, play a key role in conforming the set of indicators of performance (flow/fund ratios) describing how and why the systems are using water (Giampietro et al. 2009).

3.2 A grammar for multi-scale water-use analysis

We adapt the MuSIASEM grammar for the assessment of the coherence between water and agricultural policies in the Andarax river basin, focusing on the scenarios given by the MRBMP. The analytical definition of water is given in Table ***2*** and reflects the water services provided in the river basin that are covered in the MRBMP. In Table ***3*** we specify the resulting grammar[10] for our case study. Levels n+x give the reading external to the societal system and determine the water availability. We consider in these levels the Water Ecosystem Requirement (WER) for aquatic ecosystems, taking the ecological flows[11] (in total hm^3) proposed in the MRBMP as proxy. Green water availability is only accounted as evapotranspiration at n+3 without disaggregation into terrestrial ecosystems uses at lower levels. In the n to n-4 levels, blue water-uses are determined by the type of socioeconomic system appropriating it.

[TABLE 2 ABOUT HERE]

[TABLE 3 ABOUT HERE]

Using this grammar, we build a multi-scale matrix of water funds and flows. Data are extracted from the estimations of available resources and water-uses balances on the MRBMP (Annex II and IV) for the year 2005, reference for the current planning period. The dendogram of water uses (Figure 2) represents this matrix using e!Sankey 3.0.

3.3 Metabolic patterns of agricultural water-use

In order to link water-use to the rural metabolism, other economic and social variables commonly used in MuSIASEM grammars are deemed: the fund variables Human Activity and Colonized Land and the flow variable Gross Value Added (GVA). Combining these with water flows, we generate a set of intensive indicators (Table ***4***) for the assessment of the internal (economic, institutional) and external (biophysical) constraints of the metabolic patterns of agricultural systems. Additionally, Water Price (WP) and Energy Intensity (EI) are included due to its importance for the case: Energy costs are one of the main external constraints of water-use metabolic patterns in the Andarax and are liaised to the price of the water supply.

[TABLE 4 ABOUT HERE]

These indicators are calculated at level n-3 to develop a multi-criteria description of water-use in

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[10] Grammar (Giampietro, 2004): set of formal categories (indicators) related to the semantic definitions of what the analyst wants to measure (criteria related to relevant attributes of sustainability).

[11] Minimum water flows required permanently to maintain existent ecosystems in a water body

the different Agrarian Units shown in Figure 1. For our analysis, we will only consider those parts of the Agrarian Units that are using water coming from inside the river basin boundaries. Data are gathered from the Irrigated Land Inventory 2008 of the Andalusia Government[12], same database used by the MRBMP. None-irrigated crops are not included. Energy Intensity ratios for pumping and transport have been estimated basing on the previous studies for the urban water cycle in Almeria in Martinez 2011[13], and for water reuse in Spain in Hardy and Garrido (2010). We use the radar diagram built in LibreOfficeCalc for qualitative comparison of metabolic patterns based on an integrated set of indicators as developed by Gomiero and Giampietro (2005).

3.4 Scenarios definition

MuSIASEM can be used to generate and compare scenarios of plausible metabolic patterns. We use the previous grammar to assess the proposed scenarios in the MRBMP in 2015 and 2027. They include the increment on Irrigated Land (CL), on Efficiency (percentage of *Actual Water-Used/Water Supplied)* and the consequent variation of Human Appropriated Water from different sources. We add the Energy Intensity ratios to assess the energy costs of the new water-use pattern. The official scenarios of the MRBMP are compared with alternative scenarios drawn using what we consider a sustainability rationale based on the following assumptions:

- The increment on irrigated land maintains the same WUD (m^3/ha) than in 2005, i.e. assuming that the expansion of Colonized Land in Agriculture follows the same crop pattern than the existing one and thus the Appropriated Water will increase proportionally to the extension of hectares.
- The foreseen improvements on supply efficiency are used to decrease the Appropriated Water for agriculture.
- The Water Ecosystems Requirements are considered as None Appropriated surface water from the river.
- The Energy Intensity (KWh/m^3) associated to water primary sources is the same, i.e. assuming the same efficiency in the extraction or water production technology. Increase of energy costs associated to drip irrigation technology is not considered.
- The water-use pattern (% of water from each primary source) is established in accordance with the most energy-efficient sources available.

4 Results and discussion: Water Metabolism in the Andarax river basin

4.1 Appropriation of water in the River Basin

Figure 2 shows the multi-level representation of blue water-use in the Andarax basin in 2005. Climatic variables at level n+3 show that the bulk of year precipitation is directly evaporated and transpirated by terrestrial ecosystems. The difference between mean precipitation and

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[12] Inventario de regadíos 2008: http://www.juntadeandalucia.es/agriculturaypesca/sigregadios/servlet/regadios

[13] Martínez, J. (2011). Estudio de la Huella Energética del abastecimiento urbano de la provincia de Almería.

evapotranspiration is 44.78 hm^3 using the short recent series 1980/81-2005/06 and 75.93 hm^3 in the long historical one 1940/41-2005/06. This brings the first source of uncertainty: mean water appropriation from natural sources is estimated 47.7 hm^3 per year which is over the difference for the recent series. Indeed, the tendency to overestimate water availability by using the historical series has been strongly questioned (Aguilar and Moral 2008, 2010). This long period is not representative of current processes driving alterations in the water cycle as land use, climate change, aquifer overexploitation or reforestation. Furthermore, the Spanish WFD transposition law[14] obliges to plan water uses according to the short series.

[FIGURE 2 ABOUT HERE]

HAW at level n is higher than the TAW at n+1 due to aquifers overexploitation, while the NAW for ecosystems equal to cero in 2005. The differentiation of water sources at n+1 is essential to analyze the metabolic consequences of water use. Surface and groundwater are extracted from water natural funds, bearing a brunt on other ecological processes using that water. The bulk of water appropriation comes from groundwater, contributing to increase the already bad status of the aquifers. Alternative water sources (desalination and reuse) do not have such direct ecological impact but imply a technological boost on infrastructure and energy. Desalted water goes mainly to the urban households of Almeria city while reclaimed is devoted to agricultural production.

The Deficit included in the MRBMP for agriculture is misleading as it not only includes i) deficit due to crops irrigated under its requirements (lower water used than needed for maximum productivity) but also ii) deficit due to the foreseen increase in Colonized Land. Therefore, demands of water that are not actually happening in 2005 are accounted for, virtually increasing HAW up to 80.4 hm^3 instead of 61.3 hm^3.

4.3 Metabolic patterns of different agricultural systems

A multi-scale multi-resource representation allows us to better identify the weaknesses of the water accounting in by the MRBMP. Given the importance of the agricultural activity as driver of water-use, in this section we zoom into the n-3 level in order to characterize the metabolic performance of the different agricultural systems present in the river basin. As mentioned, institutional categories of Agrarian Units have been chosen since these are used in the MRBMP scenarios. Figure 3 shows a multi-criteria representation including the integrated set of indicators given in section 3.3. The down quadrants show the water and land use patterns based on the % of Water Used from different sources and % of Land Used for the three main crops in each Agrarian Unit. The grey line is the 50%. The upper quadrants contain a qualitative comparison of the metabolic indicators in terms of biophysical and economic performance. Data have been normalized to the range of values for all Agrarian Units, being the grey line the mean. Values of the indicators are given in Annex I.

[FIGURE 3 ABOUT HERE]

Alto Andarax and Nacimiento have at the same time a diverse crop mix (based on fruits olive grooves and fruits, mainly almond trees) and a balanced diversity of natural sources of water. Medio Andarax falls also in this pattern but relies more on groundwater than surface. Monoculture

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[14] Instruction for hydrological planning (Orden ARM/2656/2008)

open garden vegetables in Guadix, with high WUD, are located at the sources of the Nacimiento river supplying enough surface water. In Bajo Andarax, the predominance of greenhouses is feasible thanks to wastewater reclamation while in the Tabernas desert, the extension of irrigated olive groves overexploits groundwater.

Highest Energy Intensities come from the two latter areas where reclamation, transportation and 400 meters deep pumping are required for water supply. They also pay the higher water price. Both Tabernas and Bajo Andarax surpass mean Water Price of 0.082 €/m^3 for agricultural use in Andalusia. So it does Alto Andarax which is in third position in terms of Energy Intensity mainly due to transportation from surface water retention infrastructures, closely followed by Nacimiento and Medio Andarax.

In economic terms, highest productivities and work requirements are clearly liaised to greenhouse production. Olive monoculture in Tabernas show medium economic performance and, even if drip irrigation performs the lowest WUD, WUR is high because little hours of work are required. The other four have quite close WUD, 3700-4000 m^3/ha and year. Nonetheless, Medio Andarax and Guadix show low WMP at the time medium jobs generation. Alto Andarax and Nacimiento have similar medium economic performances and low work requirements.

Along with this comparative analysis, we can draw very different agricultural metabolic patterns in the watershed, responding to the three functions provision of agriculture reported in Pita and Pedregal 2011. *Pattern 1* is represented by those Agrarian Units inside Sierra Nevada National Park: Nacimiento and Alto Andarax. It responds to an environmental-territorial function of agriculture, which is a complementary activity to other jobs and has low input requirements. *Pattern 2* includes Medio Andarax and Guadix, which rely on cheap natural sources of water to maintain the economic-social function of agriculture: creating jobs. Finally, in *Pattern 3*, the economic-productive function is covered by Campo de Tabernas, thanks to natural funds capacity over-drafted and CAP subsidies to olive extension and intensive greenhouses of Bajo Andarax, techno-boosted because of continuous production along the year when natural cycles have been overcome.

4.4 Scenarios comparison

Table 5 shows a comparison of MRBMP with the alternative scenarios, used to check coherence between the proposed changes in water use by agriculture and the WFD objectives of achieving a good ecological status of water bodies and full water costs recovery. Changing variables are marked in bold.

[TABLE 5 ABOUT HERE]

All MRBMP scenarios present a raise in HAW despite increments in efficiency. In Nacimiento, no increment of CL is foreseen but in efficiency, 18% in 2005 and 26% in 2027, while HAW remains almost constant. Therefore, water *savings* achieved by new drip irrigation technology, financed through the Andalusia Programme for Rural Development (an average of 3.265 €/ha), are *reinvested* in new HAW for agriculture, resulting in even higher WUD (m^3/ha). This means that the crop pattern will change into higher %LU by those more water consuming crops.

While the MRBMP considers NAW only officially for the recuperation of Tabernas aquifer, it leaves the environmental flows (water funds to maintain ecosystems) in Nacimiento and Medio Andarax unattended. We show that these volumes could be perfectly deemed if efficiency improvements were reinvested on them and only in Medio Andarax 6% of additional water source would be needed.

The analysis of energy flows associated to the planned scenarios is missing in the MRBMP. The AIA barely mentions those associated to the irrigation *modernization* strategy. This is a dangerous lack because the main energy use of agriculture in arid regions like Tabernas is related to useful water extraction or production. In the case of Spain, the total blue water used in agriculture has only increased in 2% from 1950 until 2007 because of drip irrigation technologies while the energy use associated has multiplied by 19 (Corominas 2010).

As observed in Table 5, the water-use pattern foreseen Bajo Andarax in the MRBMP relies on desalination, which is the most energy consuming water source. This choice directly multiplies by 3.5 the TET, reaching up to 65.7 GWh/year in Bajo Andarax in 2027. Other alternatives could be considered, as wastewater reclamation that is already being used, stabilizing energetic costs at the time complying with Urban Wastewater Treatment Directive 91/271/EEC. Considering the average Energy Intensities of wastewater reuse, the resulting TET Bajo Andarax would barely increase. Current water costs do not exceed 8% of Water Monetary Productivity, but it is more than plausible that desalted water being pumped from a 50 Kms away desalination plant will raise them. When the full costs recovery principle of the WFD is implemented, not public administrations but users should cover those costs and economic sustainability of agricultural activity in the Andarax could be seriously threatened.

5. Conclusions

Water is a relevant resource for rural systems which is complex in multiple ways. These include the different scales in which water is used and the multiple services it provides. Water is an analytical continuum that connects the societal and the ecosystem levels, with different roles in each of them. The analytical connection allows us to establish a relation between the social water uses as a flow, and the ecosystem-level impacts over the water funds. This connection is done using the grammar and rationale of MuSIASEM.

The multi-scale representation of water flows opens the black box of social uses of water to show how the social structure and the institutional framework shape the metabolic pattern of water-use. In the Andarax river basin, the societal metabolism of water is mainly driven by intensive agriculture, using primarily overexploited groundwater sources but introducing alternative sources to preserve the “status-quo”. The river basin presents a situation of social scarcity as water demand already exceeded in 2005 the Total Available Water from natural funds. Even if green water was not included in this assessment, we acknowledge its importance for agriculture and terrestrial ecosystems.

A second level of complexity is given by the close connections between water and other flows and funds. The multi-criteria representation is a very versatile tool for integrated analysis of the different relevant dimensions of societal metabolism. In our study, the chosen set of indicators provides an idea of the effect that the specific land use patterns have on the water natural funds as well as the flows of energy and water required to guarantee the social and economic metabolism. We identified different metabolic patterns responding to different functions specialization of agriculture, thus of water-use: environmental-territorial, economic-social and economic-productive. These patterns are the result of dynamic interactions, entanglements and negotiations of multi-scale forces with a diversity of local realities, conforming to a globalized hybrid rurality (Woods 2007).

Energy is a key variable to assess the viability of any water management strategy that is not properly deemed by institutions. Intensification of water resource “production” fosters the dependency of agriculture from energy and can become a serious trouble in a post-peak oil context, leading to irreversible unsustainability. New water sources are promised to be highly subsidized, while the current economic crisis and public administration austerity points at opposite direction. Wastewater reclamation is a much more efficient alternative to desalination, transforming a current problem of polluting discharges into new water resource.

Another level of complexity is related to the multiple societal choices that affect water-use and therefore the impacts over water funds. These choices are frequently coming in the form of policies that regulate different parts of societal organization and might present incoherence between them. In opposition to deterministic models of closed and isolated predictions (whose outputs are “optimal solution”), the proposed MuSIASEM grammar can be adapted to each specific context to generate different integrated policy scenarios.

From the analysis we can observe that the integration of the agrarian strategy in water planning process in Andalusia blurs the ecological conservation ambitions of the WFD, slowing down the necessary transition to a new water culture. In the Andarax, increasing productivity through alternative water resources and extending cultivated land will drive an intensification of water and energy use, thus the environmental and economic costs of agricultural activity. Meanwhile, the local water administration institutionalizes a category of “virtual Deficit”, which rejects ecosystems water needs and does not consider real costs (monetary and non-monetary) of water appropriation.

In 2015, all RBMP in Europe will be evaluated and adjusted according to their efficacy towards the foreseen objectives of good ecological status of water bodies. Our proposals for the Andarax, and in turn for the Mediterranean River Basins District are: i) water availability accounting needs to be improved and real water and energy costs calculated; ii) the feasibility of new water uses needs be re-assessed in the context of financial austerity, global change and peak oil; iii) the crop pattern extension should be re-designed towards 2021 fostering less water consuming crops. In Tabernas there should be no extension of agricultural land; iv) environmental flows should be immediately incorporated as a source of future sustainability and WFD fulfillment; this is plausible to be achieved through efficiency increment; v) wastewater reclamation should be the main strategy to generate new water resources instead of desalination vi) the Rural Development Program should divert funds from the main measure of irrigation technology modernization in Axes 1 to compensation and development of other economic sources within Axes 2 and 3; vii) all this information should be transparent to society.

6. Acknowledgements

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APPENDIX 1

[TABLE 6 ABOUT HERE]

Table and table captions

Table 1. Policies driving rural change in Andalusia

	Water	Agriculture	Rural Development
European Policy	Water Framework Directive (WFD)	Common Agricultural Policy (CAP) Pillar I	Common Agricultural Policy (CAP) Pillar II
Competences in Spain	Autonomous Communities for intra-community RB, central government for inter-community RB	Autonomous Communities	Autonomous Communities, based on National Rural Development Plan
Current regional referent	Mediterranean River Basins Management Plan 2010-2015 (MRBMP)[15]	Andalusia Irrigation Agenda 2011-2015 (AIA)[16]	Andalusia Programme for Rural Development 2007-2013 (APRD)[17]

Table 2. Water uses in the Andarax and analytical role within MuSIASEM

Role	Use of water
WATER AS A FUND	Rain/Evapotranspiration Ecological flows for aquatic ecosystems maintenance
WATER AS A FLOW	Drinking and other households uses Other urban uses (services and government sectors) Agriculture & Cattle Industrial use Golf courses

Table 3. Grammar for water-use analysis

Level	Acronym	Variable	Explanation
n+3	PPT EVT	Average precipitation and real	Average precipitation and real evapotranspiration calculated in the MRBMP using two different series of precipitation: long 1940/41 – 2005/06 and short 1980/81

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[15] Agencia Andaluza del Agua. 2011. Plan Hidrológico de la Demarcación Hidrográfica de las Cuencas Mediterráneas Andaluzas.http://www.juntadeandalucia.es/medioambiente/site/portalweb/menuitem.7e1cf46ddf59bb227a9ebe205510e1ca/?vgnextoid=3bba6ff4a9743310VgnVCM2000000624e50aRCRD&vgnextchannel=75b3e6f6301f4310VgnVCM2000000624e50aRCRD

[16] Consejería de Agricultura y Pesca. 2011. Agenda del Regadío Andaluz. Horizonte 2015. http://www.juntadeandalucia.es/agriculturaypesca/portal/areas-tematicas/infraestructuras-agrarias/regadios-e-infraestructuras-agrarias/agenda-del-regadio.html

[17] Consejería de Economía y Hacienda. 2007. Programa de Desarrollo Rural de Andalucía 2007-2013. http://www.juntadeandalucia.es/agriculturaypesca/portal/la-consejeria/planes-y-politicas/programa-de-desarrollo-rural-de-andalucia-2007-2013.html

		evapotranspiration	– 2005/06
n+2	WER	Water Ecosystems Requirements	Requirements of water, in quantity and quality, to maintain existent ecosystems in a water body
n+1	AW= SUM SF GW DES REC	Available Water from different sources: Surface, Groundwater, Desalted and Reclaimed	That part of the total water resources that can be appropriated by the social system plus new “produced water sources”: wastewater reuse and desalination
n	HAW NAW	Human Appropriated Water None Appropriated Water	That part of the Total Available Water that the social systems really uses That part of the Total Available water that is left in water funds as environmental flows or aquifers recovering due to political decision
n-1	HAW_{HH} HAW_{PW}	Human Appropriated Water by Households Appropriated Water by the Paid Work sector	Water used in physiological overhead at households Water used in the economic sectors of a social system, including social public services
n-2	HAW- Rural/Urban AG OPS	Human Appropriated Water by: Rural/Urban households Agriculture Other Productive Sectors	Water used in urban (city of Almería) and rural (rest of the river basin) households. Water used in different economic sectors: Agriculture and rest of Productive Sectors, including services and government, tourism and Industry
n-3	HAW *Alto Andarax* *Medio Andarax* *Guadix* *Nacimiento* *Tabernas* *Bajo Andarax*	Human Appropriated Water by different Agrarian Units	Appropriated Water by different agriculture areas existent in the Andarax river basin

Table 4. Multi-criteria indicators of performance of agricultural metabolism of water

Criteria	Acronym	Variable	Explanation	Unit and calculation
Biophysical performance	**WUR** **(FLOW/FUND)**	Water Use Intensity	Appropriated Water per hour of Paid Work Human Activity devoted to agriculture	m^3/h HAW_i/HA_i
	WUD	Water Use	Appropriated Water per hectare of	m^3/ha

	(FLOW/FUND)	Density	Colonized Land	HAW_i/CL_i
	EI (FLOW/FLOW)	Energy Intensity	Energy used per m^3 of Appropriated Water	KWh/m^3 TET_i/HAW_i
Economic performance	**WMP** (FLOW/FLOW)	Water Monetary Productivity[18]	Gross Added Value generated per cubic meter of Appropriated Water	$€/m^3$ GAV_i/HAW_i
	WP (FLOW/FLOW)	Water Price	Price of water supply. After the WFD implementation, it should include financial, environmental and resource costs of water.	$Cts.€/m^3$ WP_i/HAW_i
	JC (FUND/FUND)	Jobs Creation	Hours of required Human Activity per hectare of Colonized Land	h/ha HA_i/CL_i
Water Use Pattern	**$WUSource_j$** (FLOW/FLOW)	Water Used from different Sources	Water Use Pattern described in % of different Water Sources	% $HAWSource_j/HAW_i$
Land Use Pattern	**$LUCrop_j$** (FUND/FUND)	Land Used by different Crops	Land Use Pattern described in % of land surface used for different crops	% $CLCrop_j/TCL_i$

Table 5: Water management scenarios for 2015 and 2027

Agrarian Unit	Indicator	Energy Intensity (kWh/m^3)	2005	2015 MRBMP	2015 Alternative	2027 MRBMP	2027 Alternative
Pattern 1 – Nacimiento	**CL**		3673	3673	3673	3673	3673
	Efficiency (%)		56	**78**	**78**	**84**	**84**
	NAW (hm^3)		0	0	**2.5**	0	**3.6**
	AW (hm^3)		14.6	**15**	**11.4**	**14**	**10.5**
	% Surface Water	0.2	61	**62**	**56**	**66**	**50**
	% Ground Water	0.72	37	**38**	**44**	**34**	**50**
	% Desalinated Water	5.25	0	0	0	0	0
	% Reclaimed Water	0.53	0	0	0	0	0
	TET (GWh)		5.6	**5.9**	**4.9**	**5.2**	**4.8**
Pattern 2 –	**CL**		2807	2807	2807	**3303**	**3303**

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[18] Tielborger et al., 2010 make an excellent advance on the concept of Water Productivity, widening it to green water and to the range of different services that water provides. Here we only consider agriculture as provisioning service and the monetary productivity of blue water.

Medio Andarax							
	Efficiency (%)		74	**84**	**84**	84	84
	NAW (hm^3)		0	0	**1.7**	0	**2**
	AW (hm^3)		10.7	**10.7**	**9.7**	**12.9**	**11.4**
	% Surface Water	0.2	35	35	**22**	**29**	**16**
	% Ground Water	0.88	65	65	**72**	**71**	**79**
	% Desalinated Water	5.25	0	0	0	0	0
	% Reclaimed Water	0.53	0	0	6	0	6
	TET (GWh)		6.9	6.9	**6.8**	**6.8**	**8.6**
Pattern 3 – Bajo Andarax	**CL**		3398	**4351**	**4351**	**4478**	**4478**
	Efficiency (%)		83	**90**	**90**	90	90
	NAW (hm^3)		0	0	0	0	0
	AW (hm^3)		18	**26.6**	**21.7**	**32.4**	**22.3**
	% Surface Water	0.2	14	**10**	**11**	**8**	**10**
	% Ground Water	1.23	43	**23**	**34**	**21**	**33**
	% Desalinated Water	5.25	0	**18**	0	**23**	0
	% Reclaimed Water	1.13	44	**50**	**55**	**48**	**57**
	TET (GWh)		19.2	**47.8**	**22.9**	**65.7**	**23.6**

Table 6. Indicators of agricultural metabolism of water for the Agrarian Units in Andarax river basin

	Alto Andarax	Medio Andarax	Guadix	Nacimiento	Bajo Andarax	Tabernas
% LU Greenhouse	0.00	0.03	0.00	0.06	0.66	0.00
% LU Cytrics	0.00	0.23	0.00	0.05	0.21	0.00
%LU Olive	0.24	0.25	0.00	0.51	0.07	0.81
%LU Fruits	0.37	0.30	0.00	0.29	0.00	0.11
%LU Open Vegetables	0.17	0.19	1.00	0.08	0.06	0.08
% WU Surface	0.71	0.35	1.00	0.62	0.14	0.05
%WU Groundwater	0.29	0.65	0.00	0.38	0.42	0.95
%WU Reused	0.00	0.00	0.00	0.00	0.44	0.00
WUR (m^3/h)	14.63	8.60	7.56	10.67	3.09	11.82
EI (kWh/m^3)	0.39	0.32	0.20	0.39	0.77	0.72

WUD (m^3/ha)	4202.44	3825.55	3784.19	3879.61	5357.84	2304.33
WMP (€/m^3)	1.82	0.79	1.33	1.19	5.43	1.29
JC (h/ha)	287.06	444.84	503.47	363.47	1736.23	194.93
WP (cnts.€/m^3)	9.02	3.60	1.00	6.90	16.13	9.16

Figure captions

Fig. 1 Andarax river basin location and spatial features

Fig. 2 Dendogram of water flows and funds in the Andarax river basin (2005)

Fig. 3 Multi-criteria representation of Agrarian Units water metabolism (2008)

Figures

FIGURE 1

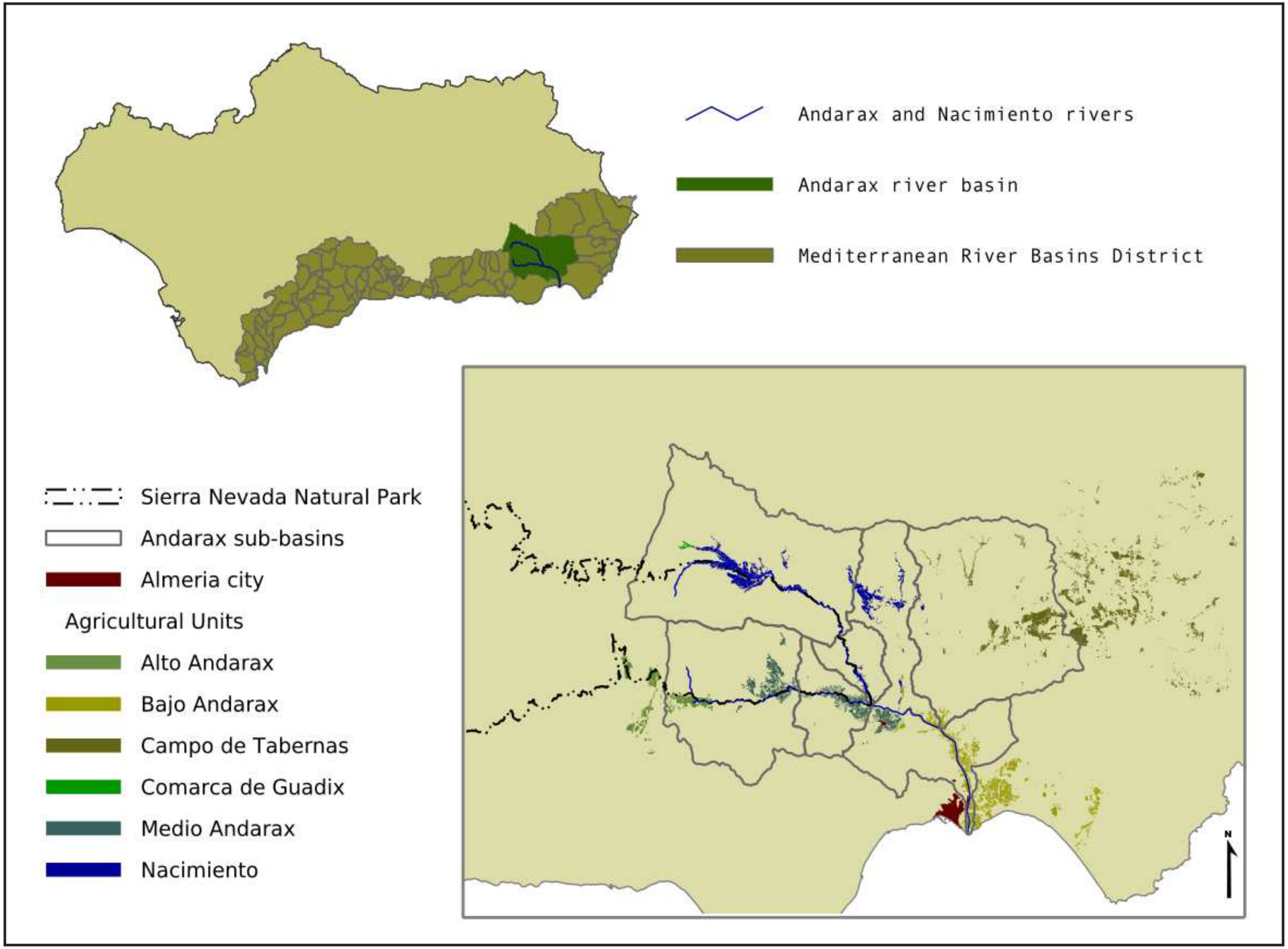

Andarax and Nacimiento rivers
Andarax river basin
Mediterranean River Basins District
Sierra Nevada Natural Park
Andarax sub-basins
Almeria city
Agricultural Units
Alto Andarax
Bajo Andarax
Campo de Tabernas
Comarca de Guadix
Medio Andarax
Nacimiento
N

FIGURE 2

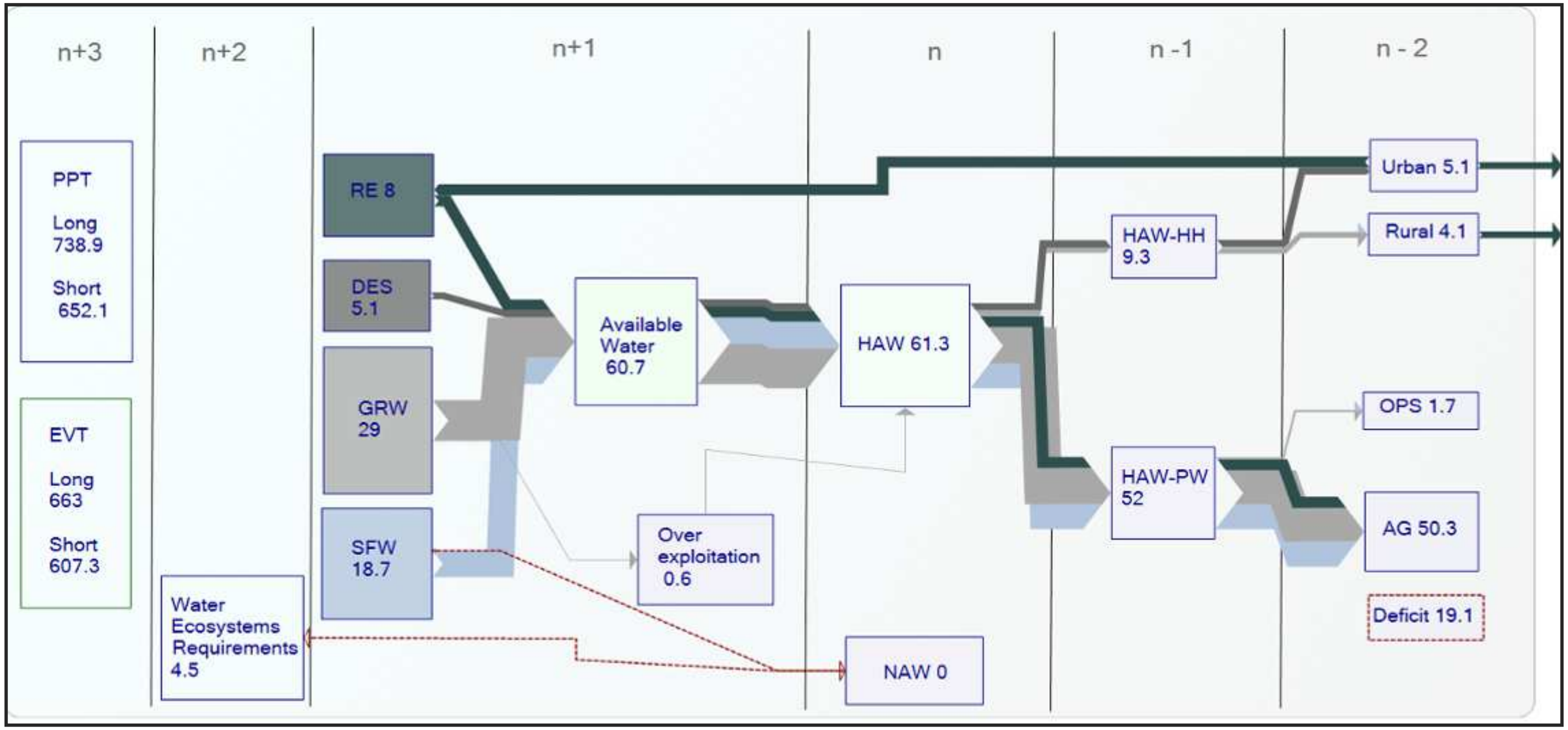
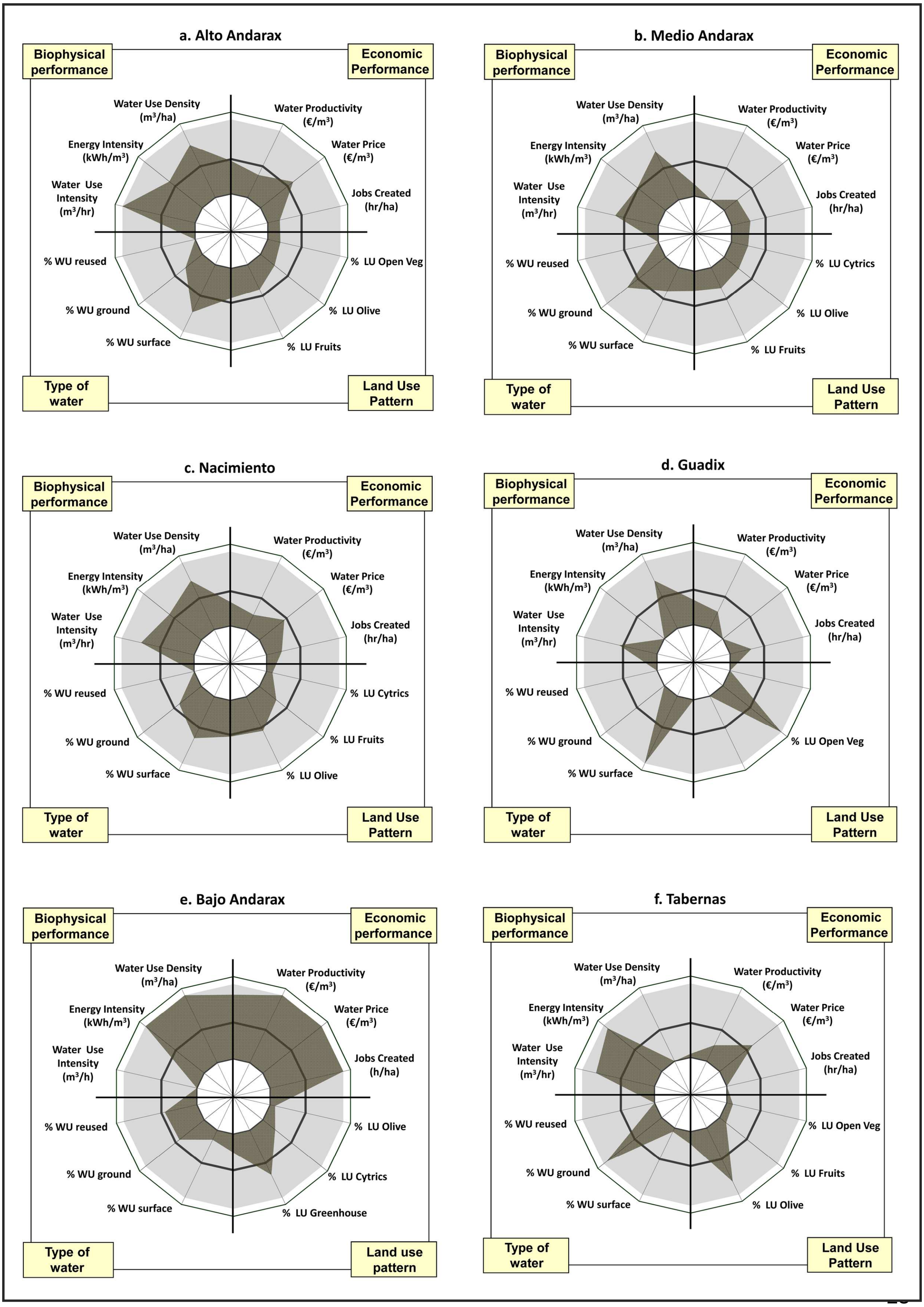

n+3
n+2
n+1
n
n -1
n - 2
PPT
Long
738.9
Short
652.1
EVT
Long
663
Short
607.3
RE 8
DES
5.1
GRW
29
SFW
18.7
Water
Ecosystems
Requirements
4.5
Available
Water
60.7
Over
exploitation
0.6
HAW 61.3
NAW 0
HAW-HH
9.3
HAW-PW
52
Urban 5.1
Rural 4.1
OPS 1.7
AG 50.3
Deficit 19.1

FIGURE 3


a. Alto Andarax
Biophysical performance
Economic Performance
Water Use Density (m³/ha)
Water Productivity (€/m³)
Energy Intensity (kWh/m³)
Water Price (€/m³)
Water Use Intensity (m³/hr)
Jobs Created (hr/ha)
% WU reused
% LU Open Veg
% WU ground
% LU Olive
% WU surface
% LU Fruits
Type of water
Land Use Pattern
b. Medio Andarax
Biophysical performance
Economic Performance
Water Use Density (m³/ha)
Water Productivity (€/m³)
Energy Intensity (kWh/m³)
Water Price (€/m³)
Water Use Intensity (m³/hr)
Jobs Created (hr/ha)
% WU reused
% LU Cytrics
% WU ground
% LU Olive
% WU surface
% LU Fruits
Type of water
Land Use Pattern
c. Nacimiento
Biophysical performance
Economic Performance
Water Use Density (m³/ha)
Water Productivity (€/m³)
Energy Intensity (kWh/m³)
Water Price (€/m³)
Water Use Intensity (m³/hr)
Jobs Created (hr/ha)
% WU reused
% LU Cytrics
% WU ground
% LU Fruits
% WU surface
% LU Olive
Type of water
Land Use Pattern
d. Guadix
Biophysical performance
Economic Performance
Water Use Density (m³/ha)
Water Productivity (€/m³)
Energy Intensity (kWh/m³)
Water Price (€/m³)
Water Use Intensity (m³/hr)
Jobs Created (hr/ha)
% WU reused
% WU ground
% LU Open Veg
% WU surface
Type of water
Land Use Pattern
e. Bajo Andarax
Biophysical performance
Economic performance
Water Use Density (m³/ha)
Water Productivity (€/m³)
Energy Intensity (kWh/m³)
Water Price (€/m³)
Water Use Intensity (m³/h)
Jobs Created (h/ha)
% WU reused
% LU Olive
% WU ground
% LU Cytrics
% WU surface
% LU Greenhouse
Type of water
Land use pattern
f. Tabernas
Biophysical performance
Economic Performance
Water Use Density (m³/ha)
Water Productivity (€/m³)
Energy Intensity (kWh/m³)
Water Price (€/m³)
Water Use Intensity (m³/hr)
Jobs Created (hr/ha)
% WU reused
% LU Open Veg
% WU ground
% LU Fruits
% WU surface
% LU Olive
Type of water
Land Use Pattern